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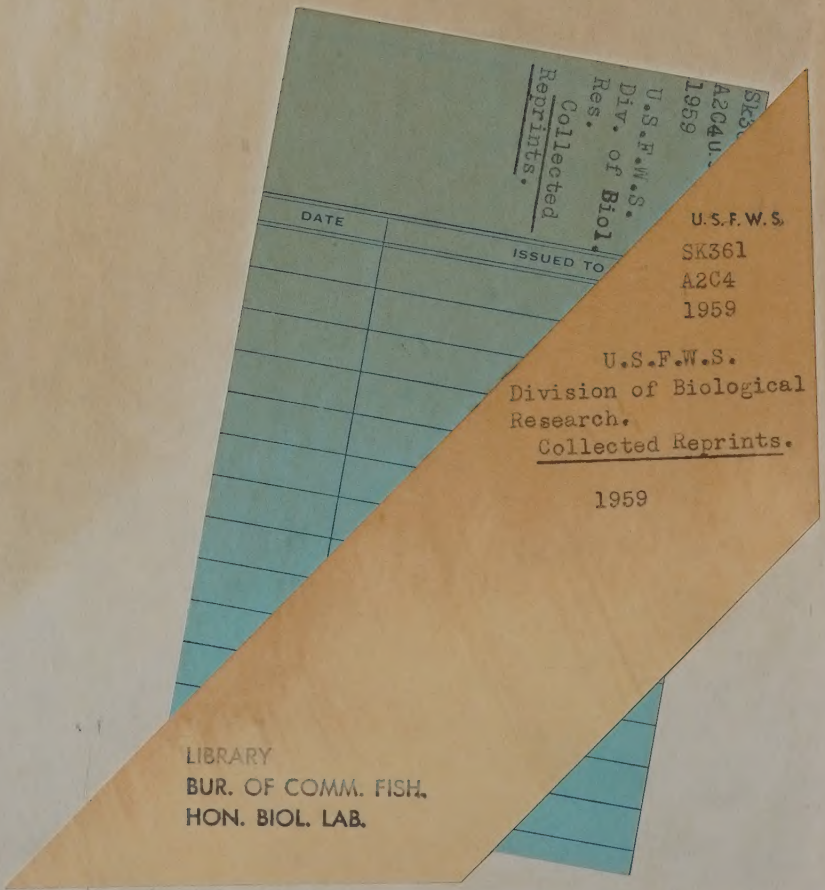

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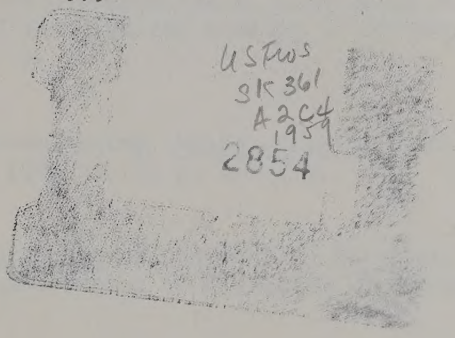
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Photoreception in the opossum shrimp, Mysis relicta Loven. Biological Bulletin, vol. 116, no. 2, p. 204-216.

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Boarfishes of the genus Antigonia of the western Atlantic. Bulletin of the Florida State Museum of Biological Sciences, vol. 4, no. 7, p. 205-250.

BERRY, FREDERICK H., AND WARREN F. RATHJEN.
A new species of the boarfish genus Antingonia from the western Atlantic. The Quarterly Journal of the Florida Academy of Sciences, vol. 21, no. 3, p. 255-258.

BRIGGS, JOHN C., AND FREDERICK H. BERRY.
The Draconettidae--a review of the family with the description of a new species. Copeia, no. 2, p. 123-133.

BROCK, VERNON E., AND ROBERT H. RIFFENBURGH.
Fish schooling: a possible factor in reducing predation. (Abstract) Proceedings of the Hawaiian Academy of Science, 34th Annual Meeting, 1958-1959, p. 32-33.

CALDWELL, DAVID K.
On the status of the Atlantic leatherback turtle Derinochelys coriacea coriacea as a visitant to Florida nesting beaches, with natural history notes. Quarterly Journal of the Florida Academy of Science, vol. 21, no. 3, p. 285-291.

Observations on tropical marine fishes from the northeastern Gulf of Mexico. The Quarterly Journal of Florida Academy of Sciences, vol. 22, no. 1, p. 69-74.

CALDWELL, DAVID K.

III. The loggerhead turtles of Cape Roman, South Carolina. The Atlantic loggerhead sea turtle Caretta caretta caretta (L.) in America. Bulletin of the Florida State Museum of Biological Sciences, vol. 4, no. 10, p. 319-348.

Notes on the crown conch, Melongena corona. Nautilus, vol. 72, no. 4, p. 117-122.

CALDWELL, DAVID K., AND WILLIAM W. ANDERSON.

Offshore occurrence of larval silver mullet, Mugil curema, in the western Gulf of Mexico. Copeia, no. 3, p. 252-253.

CALDWELL, DAVID K., AND HUGH M. FIELDS.

Surf-riding by Atlantic bottle-nosed dolphins. Journal of Mammalogy, vol. 40, no. 3, p. 454-455.

CALDWELL, DAVID K., LARRY H. OGREN, AND LEONARD GIOVANNOLI.

Systematic and ecological notes on some fishes collected in the vicinity of Tortuguero, Caribbean coast of Costa Rica. Revista de Biologica Tropical, vol. 7, no. 1, p. 7-33.

CHIPMAN, WALTER A.

The use of radioisotopes in studies of the foods and feeding activities of marine animals. Extract from the publication of the Zoological Station of Naples, vol. 31, p. 154-175.

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The scientific name of the common cod. Journal du Conseil, vol. 25, no. 1, p. 50-52.

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A field observation of mortality of marine fish larvae due to warming. Limnology and Oceanography, vol. 4, no. 2, p. 219-222.

The multiplane kite-otter as a depressor for high-speed plankton samplers. Journal du Conseil, vol. 25, no. 1, p. 29-35.

FIELDS, HUGH M.

A comparison of Trachinotus cayennensis with T. carolinus and T. paitensis. The Quarterly Journal of the Florida Academy of Sciences, vol. 22, no. 1, p. 32-40.

FISCHLER, K. J.

Occurrence of extremely small ovigerous crabs (Callinectes sp.) in coastal North Carolina. Ecology, vol. 40, no. 4, p. 720.

GEHRINGER, JACK W.

Leptoceaphalus of the Atlantic tarpon Megalops atlanticus, Valcenciennes, from offshore waters. The Quarterly Journal of the Florida Academy of Sciences, vol. 21, no. 3, p. 235-240.

KING, JOSEPH E.

Franklin gull in the central Pacific. The Condor, vol. 61, no. 3, p. 226.

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Condylostoma--an enemy of bivalve larvae. Science, vol. 129, no. 3342, p. 147.

The size and shape of metamorphosing larvae of Venus (Mercenaria) mercenaria grown at different temperatures. Biological Bulletin, vol. 117, no. 2, p. 308-318.

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Three Maine cetacean records. Maine Field Naturalist, vol. 15, no. 4, p. 111-113.

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A new method of handling longline gear. A description of POFI "tub" gear. Modern Fishing Gear of the World, p. 430-432.

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Descriptions of Euthynnus and Auxis larvae from the Pacific and Atlantic Oceans and adjacent seas. The Carlsberg Foundation's Oceanographical Expedition Round the World 1928-1930, and previous "Dana" Expeditions, Dana Report, no. 50, p. 1-34.

MURPHY, GARTH I.

Effect of water clarity on albacore catches. Limnology and Oceanography, vol. 4, no. 1, p. 86-93.

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Observations on aggressiveness in sockeye salmon smolts. Copeia, no. 1, p. 76.

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St. Johns shad fever. Florida Wildlife, vol. 12, no. 9, p. 22, 23, 39.

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Extreme loss in body weight of an American shad (Alosa sapidissima). Copeia, no. 4, p. 343-344.

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Spawning of North American herring. Transactions of the American Fisheries Society, vol. 88, no. 3, p. 164-168.

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The herring fishery of the Northwest Atlantic. Fisheries Research Board of Canada, Bulletin no. 121, p. 1-42.

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A major blood group system in Atlantic sea herring. Copeia, no. 3, p. 228-232.

SINDERMANN, CARL J., AND DONALD F. MAIRS.
Blood properties of pre- and post-spawning anadromous alewives. The Anatomical Record, vol. 134, no. 3, p. 639-640.

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The morphology and life-history of the digenetic trematode, Asymphylodora amnicolae n. sp.; the possible significance of progenesis for the phylogeny of the digenea. Biological Bulletin, vol. 117, no. 3, p. 562-581.

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Summary of experiments in the response of tuna to stimuli. Modern Fishing Gear of the World, p. 538-542.

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A study of localized predation on marked chinook salmon fingerlings released at McNary Dam. Fisheries Research Papers, vol. 2, no. 2, p. 82-83, Washington Department of Fisheries.

Fecundity of the Arctic char, Salvelinus alpinus of the Wood River, Lakes, Bristol Bay, Alaska. Copeia, no. 4, p. 345-346.

WILSON, ROBERT C., AND THOMAS S. AUSTIN.

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Tagging of skipjack in Hawaiian waters. Pacific Science, vol. 13, no. 4, p. 342-348.

PAPERS FOR WHICH NO REPRINTS ARE AVAILABLE

A. AND M. COLLEGE OF TEXAS, DEPARTMENT OF OCEANOGRAPHY AND METEOROLOGY.
Hydrological studies for the Corps of Engineers' proposed Mississippi-Gulf Outlet Project, Louisiana (Report No. 1). A. and M. Project 210, Reference 59-21T, 24 p. (processed).

AUSTIN, THOMAS S. AND VERNON E. BROCK.
Meridional variations in some oceanographic and marine biological factors in the central Pacific. (Summary in English; abstract in Russian). Preprints International Oceanographical Congress, AAAS, p. 130-132.

CALDWELL, DAVID K., FREDERICK H. BERRY, ARCHIE CARR, AND ROBERT A. RAGOTZKIE.
II. Multiple and group nesting by the Atlantic loggerhead turtle. The Atlantic loggerhead sea turtle, Caretta caretta caretta (L.) in America. Bulletin of the Florida State Museum of Biological Sciences, vol. 4, no. 10, p. 308-318.

CALDWELL, DAVID K., ARCHIE CARR, AND LARRY H. OGREN.
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CHAPMAN, CHARLES R.
Oyster drill (Thais haemastoma) predation in Mississippi Sound. Proceedings National Shellfisheries Association, vol. 49, (1958), p. 87-97.

CHIPMAN, WALTER A.
Accumulation of radioactive materials by fishery organisms. Proceedings of the Gulf and Caribbean Fisheries Institute, 11th Annual Session 1958, p. 97-110.

Disposal of radioactive materials and its relation to fisheries. Proceedings of National Shellfisheries Association, vol. 49 (1958), p. 5-12.

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The electric mid-water trawl. Maine Coast Fisherman, vol. 13, no. 11, p. 12.

Underwater TV and the fisheries (I). World Fishing, vol. 8, no. 6, p. 40-43.

Big business on the Grand Banks. The Atlantic Advocate, vol. 50, no. 2, p. 72-73, 75, 77-79, 81.

Sexual maturity of haddock. Transactions of the American Fisheries Society, vol. 88, no. 3, p. 212-213.

CLARK, JOHN R.
Seasonal changes in abundance within a community of demersal fishes. Preprints International Oceanographic Congress, AAAS (Summary in English; abstract in Russian), p. 331-332.

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Length-weight tables for Northwest Atlantic haddock. International Commission for the Northwest Atlantic Fisheries, Sampling Yearbook, vol. 2, p. 25-37.

CLARK, JOHN R., AND FRANK A. DREYER.
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The geographical history of the Argentininae. (Summary in English; abstract in German). Preprints International Oceanographic Congress, AAAS, p. 259-260.

A remarkable leptocephalus from off the coast of Washington. Letter to the Editor. Deep-Sea Research, vol. 5, p. 238-240.

COSTELLO, THOMAS J.
Marking shrimp with biological stains. Proceedings of Gulf and Caribbean Fisheries Institute, 11th Annual Session, November 1958, p. 1-6.

COUTURE, LAWRENCE H.
ICNAF mesh regulations, operation of 10 per cent annual exemption October 1, 1957, through March 31, 1951. Annual Proceedings of the International Commission for the Northwest Atlantic Fisheries, vol. 9, p. 98-100.

DALE, HARRY P.
Electronic fishing with underwater pulses. Electronics, vol. 32, no. 4, p. 31-33.

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Field tests of Petersen, streamer and spaghetti tags on striped bass Roccus saxatilus (Walbaum). Transactions of American Fisheries Society, vol. 88, no. 4, p. 319-329.

DOW, ROBERT L., DONALD M. HARRIMAN, AND LESLIE W. SCATTERGOOD.
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A quantitative analysis of marine fish communities and their seasonal and aereal variations. (Summary in English; abstract in Russian). Preprints International Oceanographic Congress, AAAS, p. 340-341.

EPPLEY, RICHARD W. AND REUBEN LASKER.
Alginase in the sea urchin Strongylocentrotus purpuratus. Science, vol. 129, 3343, p. 214-215.

FARRIS, DAVID A.
A change in the early growth rates of four larval marine fishes. Limnology and Oceanography, vol. 4, no. 1. p. 29-36.

FLEMINGER, ABRAHAM.
Distribution of Calanoid copepods in the Gulf of Mexico (Summary). Preprints International Oceanographic Congress, AAAS, p. 153-154.

FRITZ, RAYMOND L.
A summary of hake tagging in Europe and the United States, 1931-1958. Journal du Conseil, vol. 24, no. 3, p. 480-485.

GALTSOFF, PAUL S.
New for old. Sea Frontiers, vol. 5, no. 2, p. 96-100.

Ecological evaluation of the usable productivity of bottom communities. (Summary in English; abstract in Russian). Preprints International Oceanographic Congress, AAAS, p. 233-234.

GALTSOFF, PAUL S., AND D. E. PHILPOTT.
Electron microscope study of the sperm of Crassostrea virginica. (Abstract). Biological Bulletin, vol. 117, no. 2, p. 386.

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United States research report, 1958. I. Fishery and biology. Annual Proceedings of the International Commission of the Northwest Atlantic Fisheries, vol. 9, p. 87-91.

HANKS, ROBERT W.
The Maine clam: biologist reviews results of 10 years' study and controls, progress effected. Maine Coast Fisherman, vol. 13, no. 10, p. 21.

HOLT, S. J., J. A. GULLAND, C. TAYLOR AND S. KURITA.
A standard terminology and notation for fishery dynamics. Journal du Conseil, vol. 24, no. 2, p. 239-242.

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A comparison of the recent Ostracod faunas of the Gulf of Mexico and the South Atlantic coast of the United States. (Summary in English; abstract in Spanish). Preprints International Oceanographic Congress, AAAS, p. 158-160.

ISAACS, JOHN D. AND OSCAR E. SETTE.
Unusual conditions in the Pacific. Science, vol. 128, no. 3351, p. 787-788.

IVERSEN, EDWIN S., AND RAYMOND B. MANNING.
A new microsporidian parasite from the pink shrimp (Penaeus duorarum). Transactions of the American Fisheries Society, vol. 88, no. 2, p. 129-132.

JENSEN, ALBERT C.
Exotic trees from many lands find Cape hospitable. New Bedford Times, June 14, p. 35.

Cape Cod forests. American Forests, vol. 65, no. 8, p. 28-29.

JUNE, FRED C., AND J. LOCKWOOD CHAMBERLIN.
The role of the estuary in the life history and biology of Atlantic menhaden. Proceedings of the Gulf and Caribbean Fisheries Institute, 11th Annual Session, November 1958, p. 41-45.

KELLY, GEORGE F., AND G. M. CLARKE.
Table 44, United States--1957. Length frequencies--redfish. International Commission for the Northwest Atlantic Fisheries Sampling Yearbook, vol. 2, p. 161-169.

LIVINGSTONE, ROBERT J.
The use of underwater television for studying the behavior of marine fish in trawl nets. (Abstract). The Anatomical Record, vol. 134, no. 3, p. 602. Also in Bulletin Ecological Society of America, vol. 30, no. 3, p. 86.

LOOSANOFF, VICTOR L.
Some effects of pesticides on marine arthropods and mollusks. Transactions Second Seminar on biological problems in water pollution. USPHS Technical Report W60-3, p. 89-93.

Environment and larval behavior of several pelecypods. XVth International Congress of Zoology, Section III, p. 231-234.

LUX, FRED E.
A case of partial albinism in the four-spotted flounder, Hippoglossina oblonga. Copeia, no. 3, p. 253.

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McHUGH, J. L.
Can we manage our Atlantic coastal fishery resources? Transactions American Fisheries Society, vol. 88, no. 2, p. 105-110.

Review of "Living Resources of the Sea" by Lionel A. Walford. The Quarterly Review of Biology, vol. 34, no. 1, p. 79-80.

McHUGH, J. L., R. T. OGLESBY, AND A. L. PACHECO.
Length, weight and age composition of the menhaden catch in Virginia waters. Limnology and Oceanography, vol. 4, no. 2, p. 145-162.

MEAD, GILES W.
The western Atlantic jawfishes of the opisthognathid genus Lonchopisthus. Studies on the Fauna of Suriname and other Guyanas, vol. 2, no. 5, p. 104-114.

Bathypterois pectinatus, a new bathyal iniomous fish from the eastern Pacific. Journal of the Washington Academy of Sciences, vol. 49, no. 8, p. 290-292.

MERRILL, ARTHUR S.
An unusual occurrence of Mya arenaria L. and notes on other marine mollusks. The Nautilus, vol. 73, no. 2, p. 39-43.

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MILLER, DAVID.
A pelagic record of the snipefish, Macrorphamphosus scolopax (L) in the Gulf of Maine. Copeia, no. 2, p. 160.

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The early larval stages of the red hake, Urophycis chuss. Copeia, no. 3, p. 248-250.

PARSONS, JOHN W.
Muskellunge in Tennessee streams. Transactions of the American Fisheries Society, vol. 88, no. 2, p. 136-140.

PARSONS, JOHN W. AND EDWARD CRITTENDEN.
Growth of the redeye bass in Chipola River, Florida. Transactions of the American Fisheries Society, vol. 88, no. 3, p. 191-192.

POSGAY, JULIUS A.
Underwater camera as a tool for studying benthis communities. (Abstract) Preprints International Oceanographic Congress, AAAS, p. 483.

RENFRO, WILLIAM S.
Survival and migration of freshwater fishes in salt water. Texas Journal of Science, vol. 11, no. 2, p. 172-180.

RIGGS, CARL D. AND KERMIT E. SNEED.
The effects of controlled spawning and genetic selection on the fish culture of the future. Transactions of the American Fisheries Society, vol. 88, no. 1, p. 53-57.

ROUNSEFELL, GEORGE A.
Review of "On the dynamics of exploited fish populations" by R. J. H. Beverton and Sidney J. Holt. Limnology and Oceanography, vol. 4, no. 2, p. 230-231.

ROUNSEFELL, GEORGE A. AND CHARLES H. LYLES.
Seafood for sale. Texas Game and Fish, vol. 17, no. 5, p. 34-45.

SAUR, J. F., L. E. EBER, AND O. E. SETTE.
Empirical approaches to problems of interaction between atmosphere and oceanic conditions in the North Pacific Ocean. (Summary in English; abstract in German). Preprints International Oceanographic Congress, AAAS, p. 724-725.

SAUR, J. F. T., AND L. E. EBER.
On the preparation and significance of monthly mean sea-surface temperature charts of the North Pacific Ocean. (Abstract) Journal of Geophysical Research, vol. 64, no. 6, p. 694.

SAWYER, PHILIP J.
Burrowing activities of the larval lampreys. Copeia, No. 3, p. 256-257.

SEATTLE LABORATORY STAFF.
Report on the investigations by the United States for the International North Pacific Fisheries Commission 1958. Section C. International Pacific Fisheries Commission Annual Report for the year 1958, p. 74-119.

SINDERMANN, CARL J.
Zoogeography of sea herring parasites. (Abstract) Journal of Parasitology, vol. 45, no. 4, Section 2, (Supplement), p. 34.

SINDERMANN, CARL J., AND ALVA E. FARRIN.
Ecological studies of Croptocotyle lingua (Trematoda: Heterophyidae) whose larvae cause "pigment spots" of marine fish. (Abstract). Journal of Parasitology, vol. 45, no. 4, Section 2, (Supplement), p. 21-22.

STARR, THEODORE J., AND FRED SANDERS.
Some ecological aspects of vitamin B_{12} active substances. Texas Reports on Biology and Medicine, vol. 17, no. 1, p. 49-59.

STRASBURG, DONALD W.
Notes on the diet and correlating structures of some central Pacific echeneid fishes. Copeia, no. 3, p. 244-248.

STUNKARD, HORACE W.
Specific determination in the trematode genus Gymnophallus. XVth International Congress of Zoology, Section VIII, p. 672-674.

Progenetic maturity and phylogeny of digenetic trematodes (Abstract). Journal of Parasitology, vol. 45, no. 4, Section 2 (Supplement), p. 15.

Progenesis in digenetic trematodes and its possible significance in the development of present life histories. (Abstract) Biological Bulletin, vol. 117, no. 2, p. 400-401.

STUNKARD, HORACE W., AND JOSEPH R. UZMANN.
The life cycle of the digenetic trematodev Proctoces maculatus (Looss, 1901) Odhner, 1911 /syn. P. subtenuis (Linton, 1907) Hanson, 1950/ and description of Cercaria adranocera n. sp. Biological Bulletin, vol. 116, no. 1, p. 184-193.

SYKES, JAMES E., AND GERALD B. TALBOT.
Progress in Atlantic coast shad investigations--migrations. Proceedings Gulf and Caribbean Fisheries Institute, 11th Annual Session, November 1958, p. 82-90.

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Temperature and growth--the Pacific razor clam. Journal du Conseil, vol. 25, no. 1, p. 93-101.

The axiom of stable environment in fishery science. (Summary in English; abstract in Russian). Preprints International Oceanographic Congress, AAAS, p. 352-355.

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Food of yellow perch Perca flavescens (Mitchill) in Saginaw Bay, Lake Huron. Transactions American Fisheries Society, vol. 88, no. 4, p. 330-331.

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Two new flatfishes of the genus Ancylopsetta from the Guina coast. Copeia, no. 2, p. 139-148.

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Organic content of Georges Bank bottom sediments. (Summary in English; abstract in Russian). Preprints International Oceanographic Congress, AAAS, p. 587-589.

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Review of "Living resources of the sea" by Lionel A. Walford. Science, vol. 129, no. 3356, p. 1122.

Review of "Living silver" by Burns Singer. Atlantic Naturalist, vol. 14, no. 1, p. 68.

Emigration of cod, Gadus morhua L. (Summary in English; abstract in Russian). Preprints International Oceanographic Congress, AAAS, p. 358-359.

WISE, JOHN P., AND ALBERT C. JENSEN.

Movements of tagged halibut off New England. Transactions of American Fisheries Society, vol. 88, no. 4, p. 357-358.

WISE, JOHN P., AND H. E. MURRAY.

Table 38, United States--1957. Length frequencies--cod. International Commission for the Northwest Atlantic Fisheries, Sampling Yearbook, vol. 2, p. 126.

OTHER PUBLICATIONS OF THE DIVISION OF BIOLOGICAL RESEARCH

CIRCULAR

54. Research facilities of the United States Fishery Laboratory, Beaufort, North Carolina. By Gerald B. Talbot, 12 p.

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Three-year-old Pink Salmon[1]

By Raymond E. Anas

U.S. Fish and Wildlife Service
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ABSTRACT

A specimen of *Oncorhynchus gorbuscha* 552 mm in fork length, taken in the Skeena River fishery in 1956, had scales indicating two years of growth completed and substantial 3rd-year growth.

Pink salmon *(Oncorhynchus gorbuscha)* mature in two years. This characteristic is so dominant that the author could find no reference in the literature to a 3-year-old pink salmon from a North American stream. Occurrence of pink salmon older than two years has been reported in Asia, but these age interpretations are still controversial (Semko, 1954).

All pink salmon aged in the Seattle laboratory of the U.S. Fish and Wildlife Service have been 2-year-olds, with one exception. A 3-year-old pink salmon, a female, was found in samples from the Skeena River, British Columbia, collected for the International North Pacific Fisheries Commission in 1956. Figure 1 is a photograph of a scale from the 3-year-old showing the two annuli; Fig. 2 is a photograph of a typical 2-year-old pink salmon scale. The 3-year-old was identified visually in the field and in the laboratory as a pink salmon; the small scales of this species are characteristic and useful for identification. Also, the gill raker count of 11 dorsal and 17 ventral rakers identifies the 3-year-old as a pink salmon (Schultz, 1936; Clemens and Wilby, 1946).

The 3-year-old pink was 552 mm in fork length, while the 61 2-year-old fish with which it was taken ranged from 422 to 604 mm; its mid-eye to hypural plate length was 470 mm, as compared with 352–501 mm for the 2-year-olds. The weight of the 3-year-old fish was 2.42 kg, as compared with 1.03–3.43 kg for the 2-year-olds. Comparisons of scale measurements are shown in Table I.

Table I. Number of circuli and scale measurements (in mm × 42.5) of the 3-year-old pink salmon and of the sample of 61 2-year-old pinks in which it occurred. For the latter the mean, range and 99% confidence limits are shown.

	Number of circuli			Length in mm × 42.5		
	Mean	Range	99% limits	Mean	Range	99% limits
Focus to first annulus						
Age II	26	22–32	20–31	38	30–46	29–48
Age III	28	...	...	47	...	...
First annulus to edge of scale						
Age II	17	13–21	12–21	33	21–45	20–46
Age III	33	...	...	50	...	...
Total scale						
Age II	42	37–48	36–49	71	59–91	54–88
Age III	61	...	...	97	...	...
First annulus to second annulus						
Age III	26	...	...	38	...	...

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These data substantiate the visual determination that the pink salmon was 3 years old. The only scale data that are comparable between the sample and the 3-year-old are in the zone from the focus to the first annulus. All other scale data for the 3-year-old are beyond the 99% confidence limits of the sample range of values that would be expected in a *t*-distribution.

ACKNOWLEDGMENT

K. H. Mosher, U.S. Fish and Wildlife Service, corrected the manuscript and photographed the scales in Figures 1 and 2.

REFERENCES

CLEMENS, W. A., AND G. V. WILBY. 1946. Fishes of the Pacific coast of Canada. *Bull Fish. Res. Bd. Canada*, No. 68, 368 pp.

SCHULTZ, L. P. 1936. Keys to the fishes of Washington, Oregon and closely adjoining regions. *Univ. Washington Publ. in Biol.*, **2**(4): 103–228.

SEMKO, R. S. 1954. The West Kamchatka salmon reserves and their industrial utilization *Izvestiia Tikhookeanskovo N.-I. Inst. Morskovo Rybnovo Khoziaistva i Okeanografii*, (TINRO) [Bull. Pac. Sci. Inst. Fish. and Oceanog.], **41**: 3–108. Vladivostok. (Translated by Leda Sagen; available at U.S. Fish and Wildlife Service, Seattle.)

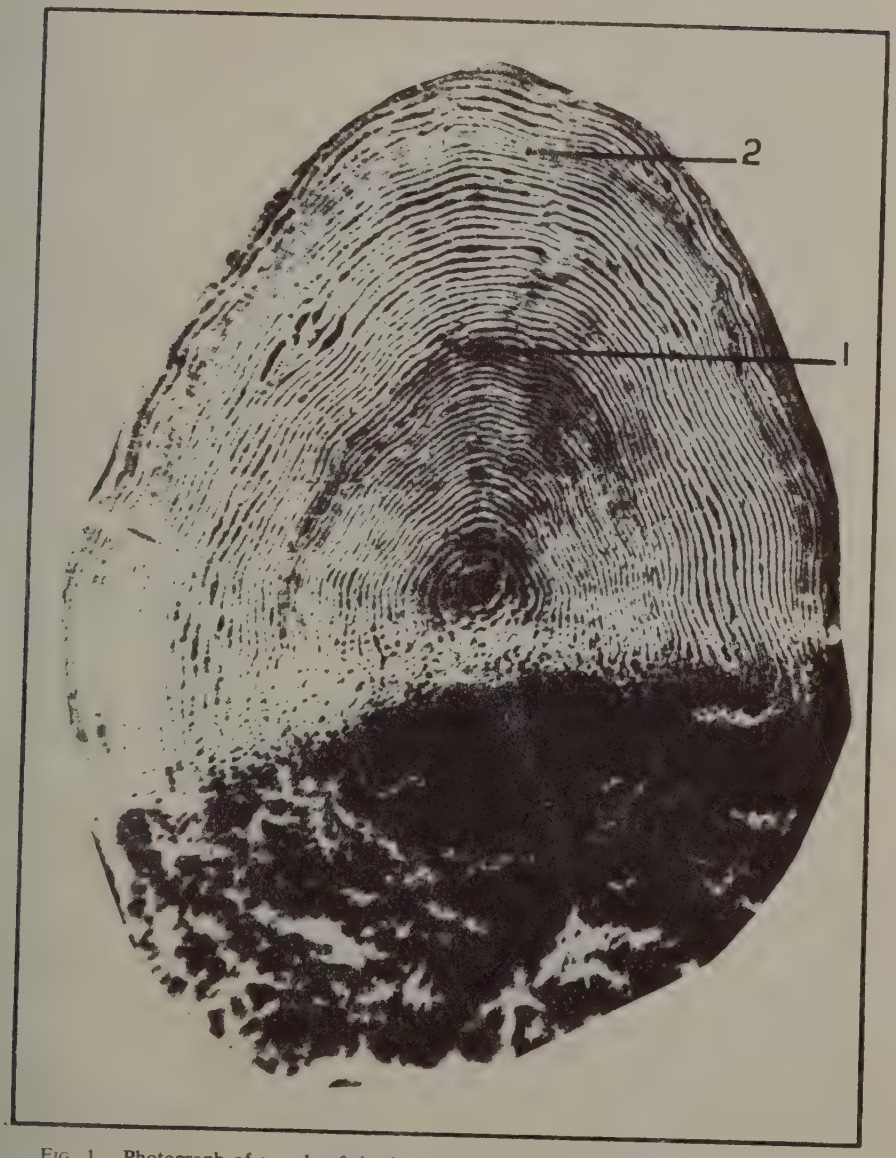

FIG. 1. Photograph of a scale of the 3-year-old pink salmon, showing the two annuli.

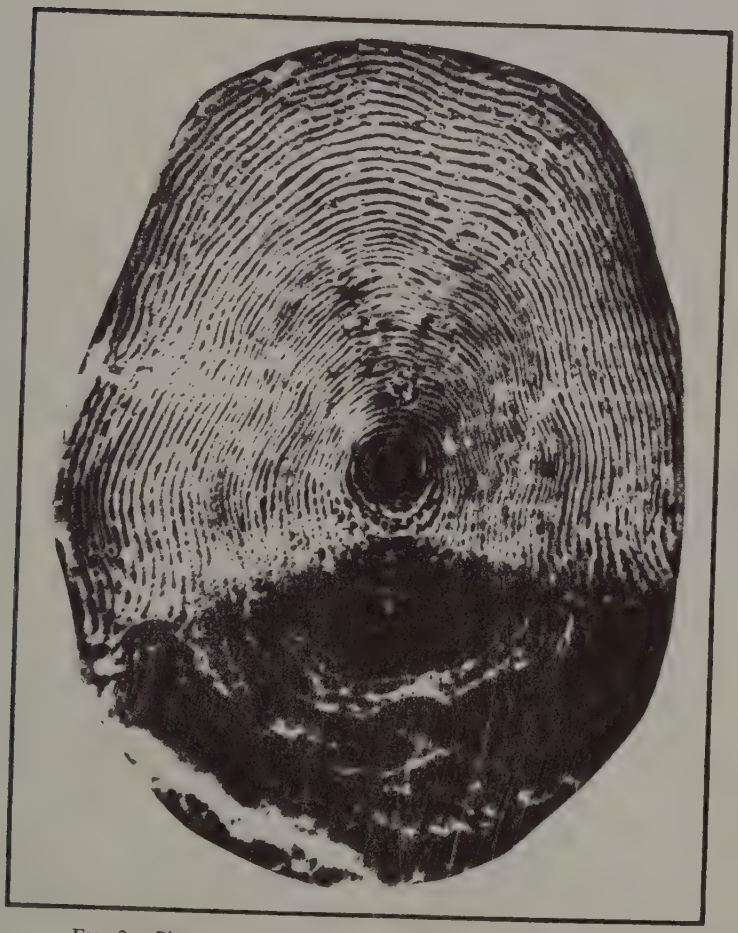

FIG. 2. Photograph of a typical 2-year-old pink salmon scale.

5. Secular Warming in Sea Surface Temperatures, Equatorial Pacific, 1955-1958

During the months of November, 1955, through January, 1956, sea surface temperatures in the eastern and central equatorial Pacific were from 0.5 to 2.5° F. cooler than normal. Subsequently, mean monthly sea surface temperatures in these areas, although exhibiting comparatively normal seasonal variation, were increasingly warmer than normal. The upper limit of the trend was reached in January, 1958, when these temperatures in the eastern central equatorial Pacific were 4°–6° F. above normal. The trend, as measured at the Christmas Island station, then reversed and by August, 1958, the temperatures were approaching the normal. A comparable reversal was not as apparent in equatorial waters to the north and south of Christmas Island.

Daily temperatures from Christmas Island in the Line Islands group, and temperatures at frequent intervals measured by Matson vessels between Honolulu and Samoa and by POFI vessels in oceanic areas near the Marquesas Islands were the principal data used for the analyses. Consideration of similar data from the north central and northeastern Pacific indicates that the higher than normal temperatures observed in the eastern and central equatorial Pacific during 1957 and early 1958 were characteristic of a large segment of the Pacific Ocean.

Although available data are as yet inadequate to confirm the hypothesis, consideration of both the surface and the subsurface temperatures (to 900 feet below the surface) near the Christmas Island station and in the Marquesan waters suggests that the above-described higher than normal temperatures during 1957 and early 1958 resulted primarily from advection and not from localized heating.

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PHOTORECEPTION IN THE OPOSSUM SHRIMP, MYSIS RELICTA LOVEN

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PHOTORECEPTION IN THE OPOSSUM SHRIMP, MYSIS RELICTA LOVÉN [1]

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Little information is available on the physiology of photoreception in the Mysidacea other than a few studies of phototaxis. Practically nothing is known of their spectral sensitivity, dark-adaptation, or lower limits of vision. The two observations that have been made on the response of the opossum shrimp, *Mysis relicta* Lovén, have shown that they swim downward when subjected to light (Dakin and Latarche, 1913) and are especially sensitive to a combination of high temperature and bright light (Larkin, 1948). The present study of the spectral sensitivity, dark-adaptation, and phototaxis of *M. relicta* was undertaken to add to our information on the physiology of photoreception.

Materials and Methods

Mysis relicta is ideal for a study of this nature, since its large size (average length, 15.0 mm.) facilitates observation, and a laboratory population can be easily maintained. The animals used in this study were collected in Lakes Huron and Michigan.

All experiments were conducted in a cold-room under controlled light conditions and at a constant temperature of 10° C. The dark-adaptation and special sensitivity studies were carried out in an all-glass aquarium 12.0 by 8.0 by 3.0 inches, filled to 1 inch from the top. A 24-inch glass tube, with a 1-inch diameter, was used in the experiments on phototaxis.

Under conditions of continuous darkness or light, the mysids normally rested on the bottom of the tank, periodically making short excursions off the bottom. If the experimental light was turned on when the mysids were swimming upwards, they hesitated momentarily, turned, and swam rapidly to the bottom of the aquarium. This momentary hesitation was found to be a reliable indicator for the photic response.

The difficulty of observation in a dark room was met by using an infra-red viewer and infra-red light source or a large Fresnel lens to focus low-intensity red light (approximately 0.001 foot-candle) on the observer's eye. The red light was produced by a neon glow lamp and a number 2404 Corning glass filter, transmitting wave-lengths of 620 mμ and greater. It was permissible to use this light for viewing, since preliminary studies had established that *M. relicta* was almost completely insensitive to the red region of the visible spectrum in the 620-

[1] Based on a thesis submitted in partial fulfillment of the requirements for the Ph.D. degree, University of Michigan, 1958.

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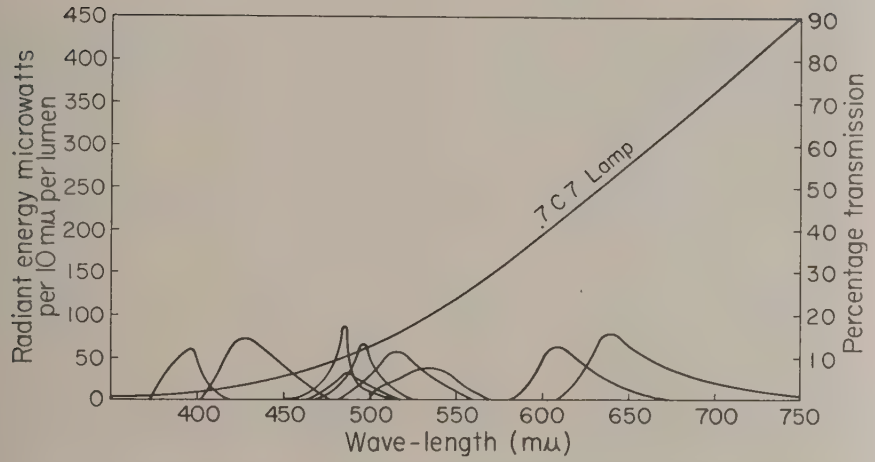

FIGURE 1. Spectral distribution of a tungsten filament lamp (color temperature 2300° K) and the spectral transmission of monochromatic filter combinations.

to 700-mμ wave-band. Mysid behavior was the same when viewed by either of the above methods.

A General Electric 7C7 tungsten filament lamp suspended 3 inches above the water surface provided the light source for the spectral sensitivity studies. This lamp has an average color temperature of approximately 2300° K and its lumen output averages 45. Although the exact distribution curve of spectral energy was not available for the lamp, a reasonably accurate curve was constructed by extrapolation from data supplied by the Nela Park Laboratory of General Electric (Fig. 1).

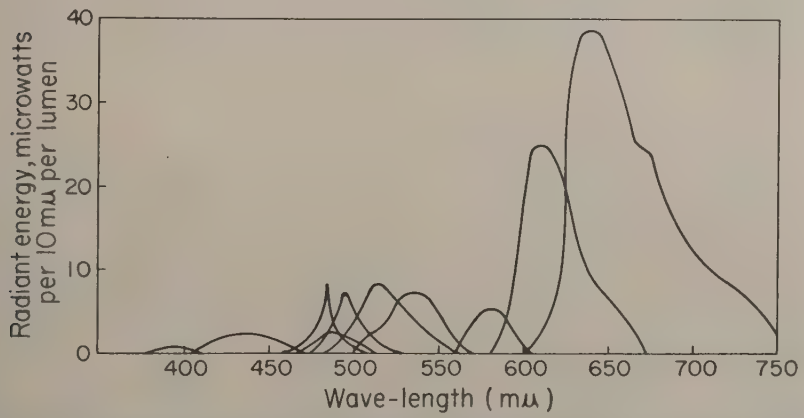

FIGURE 2. Radiant energy output from a tungsten filament lamp (color temperature 2300° K) through various monochromatic filter combinations.

Nine monochromatic-filter combinations were made with Corning glass color filters and interference filters; Figure 1 gives the spectral transmission of these filter combinations. The total energy output of a given filter combination was calculated by multiplying the energy available (in 10-mμ-wide wave-bands) from the lamp by the percentage transmission of the filter combination (Fig. 2). The percentage transmission of the various filter combinations was obtained either from data supplied by Corning (1948) or with a Beckman DU Spectrophotometer. The range of intensities for a particular wave-band was obtained by the use of evaporated-metal, neutral-density filters, having optical densities of 0.6, 0.9, and 1.0.

The reaction times of the mysids to the various intensities of radiant energy were measured by a stop watch. Sufficient time was allowed between successive tests to keep the mysids completely dark-adapted.

In the dark-adaptation experiments, the mysids were first subjected for 3 minutes to the intense light of a 1000-watt photoflood lamp. At the end of the 3-minute period all lights were turned off except the viewing light. Then the mysids were subjected to flashes of light, approximately 0.1 second in duration, of a given intensity. These flashes were spaced at 1- to 3-minute intervals. The experimental light was a 6-watt, 9-foot-candle, 115-volt, tungsten-filament lamp suspended 3 inches above the water surface. The intensity of the light was altered by interposing various numbers of evaporated-metal, neutral-density filters, each having an optical density of 1.0. The time in the dark, prior to first stimulation, was measured by stop watch.

In the experiment on the phototactic response of *M. relicta,* six individuals were placed in a 24-inch glass tube, with a 1-inch diameter, lying horizontally to eliminate any gravitational effects. The experimental light, a 7C7 lamp, was suspended 1 foot above the midpoint of the tube. After the mysids had been subjected for measured intervals to total darkness or light, one-half of the tube was shaded and the number of mysids in the unshaded half of the tube was recorded at 30-second intervals for a 5-minute period. First the right and then the left half of the tube was shaded to detect any bias in the distribution of the mysids. Control runs, with neither half being shaded, were made at frequent intervals.

Spectral Sensitivity

Earlier studies of spectral sensitivity

It has been well established that the first step in the response to light in any animal is a photochemical reaction. Hecht's (1919, 1920, 1921) work on the clam, *Mya arenaria* Verrill, contributed much toward establishing the photochemical nature of photoreception. He demonstrated that the fundamental concept of photochemistry, the Bunsen-Roscoe reciprocity law which holds that the photochemical effect is equal to the product of time and intensity, could be applied to the data of his studies.

Before a photochemical reaction can occur, light must be absorbed. The absorption spectra of the visual pigments will therefore determine the effects on the photoreceptor and in turn the response of the organism. The behavioral response of an organism to different regions of the radiant-energy spectrum has

given rise to the concept of "action spectra." For example, if a visual pigment has its absorption peak at a wave-length of 500 mμ, the animal possessing this visual pigment would be most sensitive to this wave-length. This concept has led to a number of action-spectrum studies on invertebrates. Mast (1917) re-

TABLE I

Reaction time (seconds) of Mysis relicta to various wave-lengths of light at several intensities (Unless noted otherwise the neutral-density filters transmitted 10 per cent of the light)

Wave-length of peak transmission (mμ)	Number of neutral-density filters	Energy output of 7C7 lamp through filters (microwatts/10 mμ/ lumens)	Average reaction times for 10 trials (seconds)	Standard deviation
395	0	2.20	0.77	0.18
395	*1	0.26	0.88	0.12
395	2	0.02	1.16	0.39
430	0	11.19	0.72	0.06
430	**1	2.80	0.84	0.06
430	*1	1.34	0.86	0.31
430	***2	0.34	0.92	0.16
430	****3	0.03	1.15	0.39
485	0	7.63	0.87	0.14
485	1	0.76	1.04	0.12
485	2	0.08	1.18	0.10
488	0	13.63	0.86	0.19
488	2	0.14	1.13	0.20
496	0	14.93	0.77	0.24
496	1	1.49	0.82	0.11
496	2	0.15	0.98	0.14
515	0	32.98	0.64	0.13
515	1	3.30	0.71	0.20
515	2	0.33	0.83	0.21
515	3	0.03	1.01	0.19
515	4	0.003	1.42	0.36
540	0	29.85	0.84	0.15
540	1	2.99	0.92	0.06
540	2	0.30	0.95	0.22
540	3	0.03	1.33	0.25
610	0	108.94	1.10	0.17
610	1	10.89	1.10	0.09
610	2	1.09	1.33	0.36
640	0	256.11	1.13	0.31
640	1	25.61	1.22	0.43
640	2	2.56	1.32	0.45
640	3	0.26	(No reaction)	...

* Neutral-density filter transmitting 12 per cent of the light.
** Neutral-density filter transmitting 25 per cent of the light.
*** Filters 1 and 2 combined.
**** Neutral-density filter transmitting 10 per cent of the light combined with filters 1 and 2.

ported peak sensitivity to light at the following wave-lengths: 483 mμ in *Euglena, Arenicola, Trachelomonas,* and *Lumbricus;* 524 mμ in *Pandorina* and *Eudorina;* 503 mμ in *Chlamydomonas,* and blowfly larvae. Hecht (1921) established the basis for future studies through his experiments on *Mya arenaria.* This clam

had a maximum sensitivity at 490 mμ. Most insects apparently have two peaks of maximum sensitivity, 365 mμ and 492 mμ (Weiss, 1943).

Results obtained through the methods of these investigators are similar to those secured by *in vitro* studies of the spectral absorption of squid rhodopsin (Bliss, 1948). An electrical method has been employed to determine the spectral sensitivity of the eyes of *Limulus* (Graham and Hartline, 1935), a grasshopper, *Melanoplus* (Jahn, 1946), and the diving-beetle, *Dytiscus* (Jahn and Wulff, 1948). These studies demonstrated, as did the behavior method of Weiss, that the arthropod eye has a peak sensitivity in the green region of the spectrum.

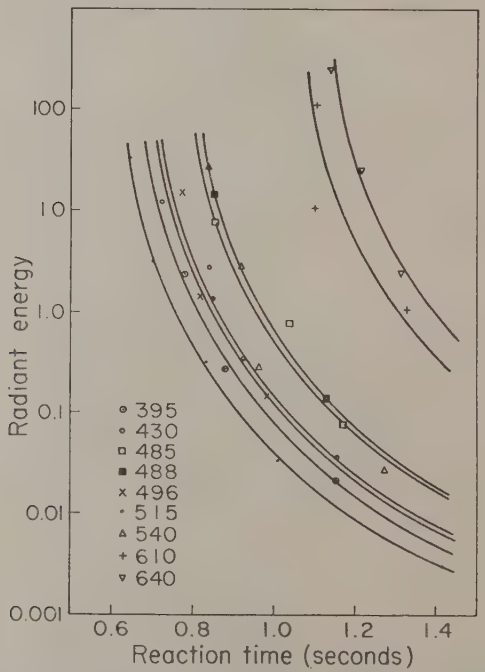

FIGURE 3. Reaction rate of *Mysis relicta* to certain wave-lengths (mμ) of light at various intensities. (Each point represents the average reaction time for 10 trials.)

The only source of information on the sensitivity of mysids to various regions of the spectrum is Hess' (1910) study of the phototactic response of a marine mysid to certain regions of the visible spectrum. Sixty-four mysids were placed in the dark and then subjected to a continuous spectrum of light. The mysids swam toward the light and aggregated in certain regions of the spectrum: 40 in the yellow-green, 19 in the blue and violet, and 5 in the red. When the position of the spectrum was altered the mysids followed the yellow-green band.

Spectral sensitivity in M. relicta

The dark-adapted mysids reacted to the different regions of the spectrum with the typical photic response but the time of reaction varied with wave-length. The mysids reacted most quickly at wave-lengths in the vicinity of 515 mμ and 395 mμ (Table I). The reaction times at wave-lengths of 610 mμ and 640 mμ were much slower (Fig. 3) despite the fact that considerably more energy was available in the red region of the spectrum than in the blue region (Fig. 2). If the mysid eye were equally sensitive to all regions of the spectrum, the faster reaction time

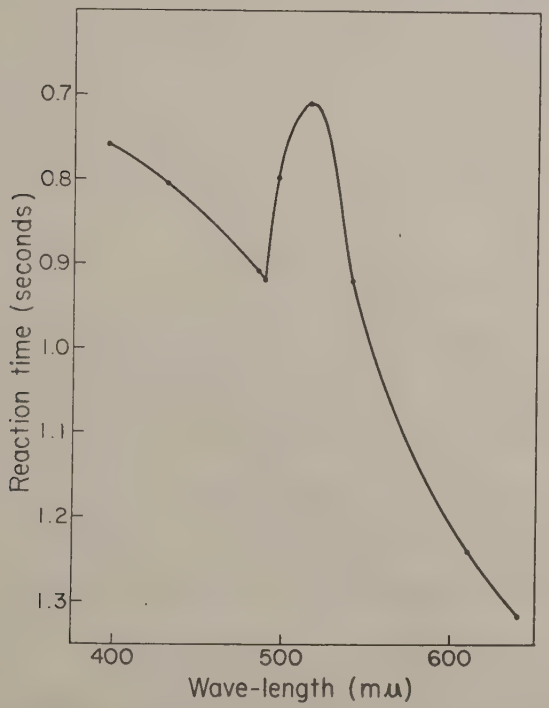

FIGURE 4. Action spectrum of the dark-adapted *Mysis relicta* eye.

would have been elicited by the higher energy of longer wave-lengths. The speed of response decreased progressively as the wave-length increased from 395 mμ to 488 mμ (Fig. 3). Then the trend was reversed and the mysids responded progressively faster as the wave-length increased. The reaction time at a wave-length of 496 mμ was similar to that recorded at 430 mμ and the quickest response was elicited by light with peak energy at 515 mμ. The reaction to light with wave-lengths longer than 515 mμ became progressively slower as the wave-length increased.

The reaction times of the mysids to a wide range of intensities for a particular

wave-length were determined through the use of evaporated-metal, neutral-density filters. Similar reaction times could be obtained for different wave-lengths by altering the intensity. Approximately 1000 times more radiant energy was required in the red region than in the blue-green region of the spectrum before equal reaction times could be obtained. The curves resulting from a plot of the reaction time against the radiant energy available from the 7C7 lamp and the filter combinations show that the reaction time varies inversely as the logarithm of the light intensity (Fig. 3). It is apparent that the rate of response to different wave-lengths was caused by differences in the ability of the eye to absorb energy at various wave-lengths.

The reaction times for a definite energy value of 3 as determined from the curves in Figure 3 were plotted against the transmission peaks of the monochromatic filter combinations to give an "equal-energy" curve. The resulting curve is the "action spectrum" or spectral sensitivity curve for *M. relicta* (Fig. 4). The mysids have a maximum sensitivity to light with a wave-length of approximately 515 mμ; another peak of sensitivity occurs in the violet region of the spectrum at or below 395 mμ. This suggests that the mysid eye contains at least two visual pigments.

Dark-Adaptation

Earlier studies of dark-adaptation

All of the photoreceptors studied by various investigators have shown an increased sensitivity to light after a period in darkness. This reaction has given rise to the concept of dark-adaptation, a process that has been studied by several different methods, including behavior. Studies on *M. relicta* have been made by a procedure similar to a behavioral method employed by Hecht (1919) to study dark-adaptation in *Mya*.

The behavior method for determining dark-adaptation has produced data that are similar to those obtained by *in vitro* resynthesis of bleached rhodopsin (Chase and Smith, 1939) and by measuring the electrical response of the eyes of *Limulus* (Hartline, 1930).

I could not find any published account of previous studies on dark-adaptation in Mysidacea.

Dark-adaptation in M. relicta

The 3-minute exposure of the mysids to the photoflood lamp evidently caused a bleaching of the visual pigment. The mysids did not respond to any light for at least 30 seconds after the lamp was turned off. Response to the experimental light after a period in darkness would indicate, therefore, that sufficient visual pigment had been resynthesized for photoreception. The light intensity necessary to elicit a response after a period in the dark was considered the "threshold intensity."

The light intensity required to produce a reaction decreased with the increase of time spent in the dark (Fig. 5). Several repetitions of this experiment gave closely similar results. The increase in sensitivity was relatively fast during the first 57 seconds, and then somewhat slower. The upper part of the curve probably lies too far to the right, since the mysids did not start to swim up until at least

30 seconds after the photoflood light was turned off; consequently, it was impossible to determine their sensitivity during this period. Possibly the steeper slope in the upper part of the curve can be attributed to a state of shock from exposure to the intense light. The initial recovery of sensitivity of the mysid eye, therefore, may progress at a rate other than indicated by the upper part of the curve in Figure 5. Light intensity values of 9×10^{-2} foot-candle and below

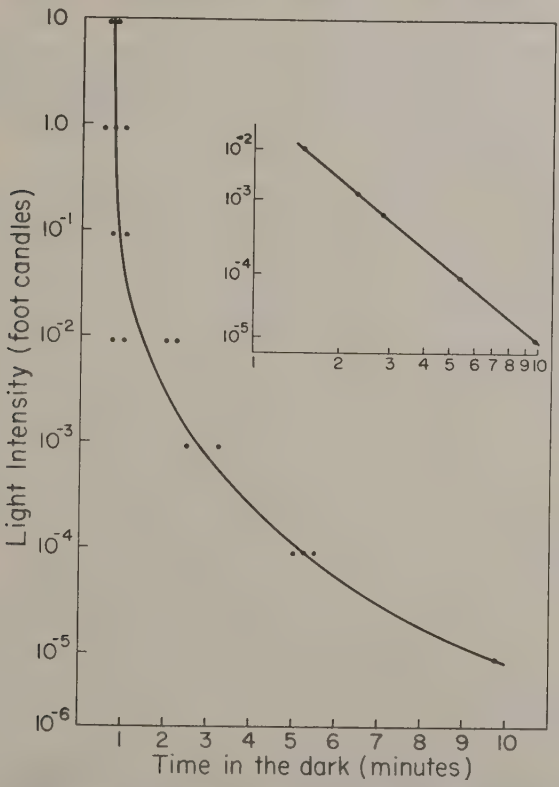

FIGURE 5. Dark-adaptation of *Mysis relicta*. Threshold intensity is plotted as ordinate against time in the dark as abscissa. Inset is the plot of log of threshold intensity against log of time in the dark.

and time in the dark gave a straight line when plotted on a logarithmic scale. These curves closely resemble that for a bimolecular reaction.

Although a precise determination of the lowest limits of visual sensitivity could not be made, a definite response to a light intensity of 10^{-6} foot-candle was established. In all probability the mysids can detect even a much weaker light.

The question arises as to whether the stimulating flashes themselves have any effect upon the dark-adaptation of the eye. Hartline (1930) believed that if they are widely spaced in time, 3 to 5 minutes, they have little effect.

Phototaxis

Earlier studies on phototaxis

Photoreception is important for the normal orientation of mysids. Delage (1887) established that the statocysts of mysids have a balancing function, but it was subsequently demonstrated that if the statocysts are removed, the eyes make possible normal orientation in the light (von Buddenbrock, 1914). The mysids always kept their dorsal side oriented toward the light—a reaction termed the "dorsal light reflex." Additional studies on three different species of mysids have shown that orientation is governed by responses to a combination of gravitational and light stimuli (Fraenkel, 1931; Foxon, 1940). Fraenkel suggested that light stimulates the mysids to assume a position whereby a definite region of the statocyst is stimulated by gravity.

The phototactic responses of mysids are varied and complex. Keeble and Gamble (1904) reported that the phototactic sign changed from positive to negative when the mysids were moved from a white to a black background. Bauer (1908) found that mysids remained at the bottom of an aquarium when light came from above and were positively phototactic to a lateral light. Menke (1911) concluded that *Hemimysis lamornae* was positively geotactic and negatively phototactic. He also removed the statocyst and interpreted the mysids' subsequent failure to leave the bottom as a pronounced negative phototaxis. Recent research has shown that this behavior may be a "general position reflex" whereby mysids utilize the tactile sense for orientation along with the "dorsal light reflex" (Foxon, 1940). Some differences in response can be related to age. Adults of *Neomysis vulgaris* [*N. integer* Leach] are more strongly photonegative than are the young (Lucas, 1936). Mysids have been shown to be telotactic; when two light rays are crossed at right angles they react to one light source and ignore the other. Light-adapted individuals also have shown a reversal in the phototactic sign by swimming to and fro in the direction of the incident light (Fraenkel, 1931).

The observations of other workers that certain marine mysids possess a diurnal rhythm in their chromatophore system (Keeble and Gamble, 1904) suggested the possibility of a similar periodicity in the phototactic responses of *M. relicta*. Their investigations of the chemical conditions of the mysid's tissues indicated the possibility of a metabolic periodicity. The liver and muscle tissues were alkaline in the morning and became progressively acid during the day. Some of the experimental work which Menke (1911) conducted led him to postulate that *Hemimysis lamornae* was negatively phototactic during the day and positively phototactic at night. The experiment described in the next section was devised to detect such a periodicity in *M. relicta*. Although the results were not conclusive on that point, other important findings warrant inclusion of these data in this paper.

Phototaxis in M. relicta

Whenever the control runs were conducted the distribution did not differ significantly from random. The distribution did differ significantly (Chi Square test) when one-half of the tube was shaded after the mysids had been in the dark or light for a period of time. The mysids were photopositive unless they had been subjected to total darkness for 10 hours; then they became photonegative

(Table II). The photonegative condition persisted for only a short time as they became light-adapted within 6 minutes. On August 15 at 11:54 Eastern Standard Time (EST) the mysids were definitely photonegative after being in the dark for 13 hours; after exposure to the experimental light for 6 minutes they tended to be photopositive. On the same date at 21:06 EST the mysids still responded photopositively after approximately 4 hours in the dark. Similar results were

TABLE II

Phototactic response of M. relicta to a constant light intensity after periods in light and in total darkness. [Observations were made of the distribution of 6 animals at 30-second intervals for 5 minutes, except at 21:12 (5½ minutes), 11:55 (2½ minutes), 11:58 (2½ minutes). Numbers in parentheses indicate control run, i.e., entire tube unshaded. Asterisk indicates significant Chi Square value at 5 per cent level. Experiments were started at 20:54 EST on August 14, 1956, and completed at 12:06 EST on August 18, 1957]

Time (EST)	Time in dark		Time in light		Number in portion of tube		Chi Square
	Hours	Minutes	Hours	Minutes	Shaded	Unshaded	
20:54	—	—	2	54	18	42	9.6*
11:54	13	5	—	—	51	9	29.4*
12:03	—	—	—	6	25	35	1.66
13:05	—	—	1	8	9	51	29.4*
13:11	—	—	1	14	17	43	11.27*
13:37	—	21	—	—	27	33	0.6
16:38	—	—	—	—	(30)	(30)	0.0
16:51	—	—	2	56	19	41	8.06*
21:06	4	10	—	—	12	48	21.6*
21:12	—	—	—	6	28	38	1.51
21:17	—	—	—	—	(31)	(29)	0.066
10:19	12	57	—	—	36	24	2.4
10:25	—	—	—	6	43	17	11.26*
10:31	—	—	—	—	(28)	(32)	0.266
12:13	1	36	—	—	34	26	1.066
12:19	—	—	—	6	17	43	11.26*
12:24	—	—	—	—	(29)	(31)	0.066
22:43	10	14	—	—	41	19	8.06*
22:48	—	—	—	5	35	25	1.66
21:28	3	38	—	—	26	34	1.06
21:34	—	—	—	6	21	39	5.4*
21:39	—	—	—	—	(34)	(26)	1.06
11:55	14	10	—	—	20	10	3.32
11:58	—	—	—	3	14	15	0.132
12:06	—	—	—	—	(33)	(27)	0.6

secured on August 16 at 10:19 EST and August 18 at 11:55 EST, the mysids were photonegative after 13 and 14 hours in the dark. At 22:43 EST on August 16 they were photonegative after 10 hours and 14 minutes in the dark. The fact that the mysids could be photonegative either in the morning or at night indicates that the phototactic response does not have a persistent diurnal rhythm. Existence of the photonegative condition depends on the amount of time in the dark.

Experiments revealed also that if the light intensity was increased rapidly by

1 or 2 foot-candles, the mysids swam into the shaded area, although they previously had been definitely photopositive. They adapted to this increased intensity within 2 minutes. Johnson (1938) obtained similar results with the copepod, *Acartia clausii* Giesbrecht. These copepods were placed in a glass cylinder and subjected to a step-wide change in intensity. The more rapid the change in intensity, the greater was the response. The copepods were photopositive after a period in the dark, but they swam away from the light when the intensity was increased.

Discussion

The experiments indicate that *Mysis relicta* has at least two visual pigments, one with an absorption peak at 515 mμ and another with a peak at or below 395 mμ. The maximum sensitivity at 515 mμ probably is important to the mysid for orientation in the environment, since light with a wave-band of 490 mμ to 540 mμ penetrates to considerable depth in Lake Huron (Beeton, 1958). The importance of the sensitivity to violet light (395 mμ) is not obvious, since light with a wave-band of 300 mμ to 420 mμ does not penetrate into the deep-water habitat of the mysids. Ultraviolet light has been found to cause negative phototaxis in *Daphnia pulex* (Moore, 1912), and *D. magna* (Baylor and Smith, 1957). In view of the deleterious effect of ultraviolet light, it is not surprising to find that many arthropods are sensitive to short wave-lengths and photonegative to ultraviolet light.

The mysids are able to "dark-adapt" at a relatively fast rate. This increase in sensitivity is interpreted as a function of the amount of regenerated visual purple available at each moment in the dark. The curve describing the progress of this reaction resembles that for the equation for a bimolecular reaction. The literature, however, reveals considerable disagreement as to whether the dark-adaptation data are fitted best by the equation for a bimolecular or monomolecular reaction. The reaction is probably bimolecular, but appears monomolecular when one of the reactants is in excess. Some of the discrepancies in the results obtained by different workers may possibly be explained, in part, by the data of Haig (1941). Haig's data showed that the curve of recovery after adaptation to a low intensity is decidedly different from that of recovery after adaptation to high intensity of illumination. Hartline and McDonald (1947) presented a similar series of recovery curves for single visual elements of *Limulus* after exposure to light of different intensities.

The change in the phototactic response of *M. relicta* is related to the prior presence or absence of light. Time also is involved, since the mysids were photopositive unless they had been subjected to total darkness for 10 hours or more; then they responded photonegatively.

Changes in the phototactic sign may be related to the activity of the organism. The mysids were very active in the light and not as active in the dark; possibly the increased activity results in an acidic condition in the tissues. The acidity would decrease with reduced activity. *Daphnia*, copepods, *Gammarus* (Loeb, 1918), and *Hemimysis* (Franz, 1911) can be made positively phototactic by adding a weak acid to the water. The assumption of a metabolic change due to differences in activity does not account for the rapid change from a photonegative to a photopositive condition. The possibility remains that light may control a chemical cycle in the organism. A compound, responsible for the photonegative

condition, may be broken down upon exposure to light. It may require a long period of darkness for resynthesis of this compound.

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LITERATURE CITED

Bauer, Victor, 1908. Über die reflektorische Regulierung der Schwimmbewegungen bei den Mysiden mit besonderer Berücksichtitung der doppelsinnigen Reizbarkeit der Augen. *Zeitschr. f. allgem. Physiol.*, **8**: 343–369.

Baylor, Edward R., and Frederick E. Smith, 1957. Diurnal migration of plankton crustaceans. Rec. Adv. Invert. Physiol.; University of Oregon Publication; pp. 21–35.

Beeton, Alfred M., 1958. Relationship of Secchi disc measurements to light penetration in Lake Huron. *Trans. Amer. Fish. Soc.*, **87**: 179–185.

Bliss, A. F., 1948. The absorption spectra of visual purple in the squid and its bleaching products. *J. Biol. Chem.*, **176**: 563–569.

Chase, Aurin M., and Emil L. Smith, 1939. Regeneration of visual purple in solution. *J. Gen. Physiol.*, **23**: 21–39.

Corning Glass Works, 1948. Glass color filters. Bulletin C-248. Corning, New York, 21 pp.

Dakin, W. J., and M. Latarche, 1913. The plankton of Lough Neagh: a study of the seasonal changes in the plankton by quantitative methods. *Proc. Roy. Irish Acad., Ser. B*, **30**: 20–96.

Delage, V., 1887. Sur une fonction nouvelle des otocystes commes organes d'orientation locomotrice. *Arch. Zool. Expér. Gén., Sér. 2*, **5**: 1–26.

Foxon, G. E. H., 1940. The reaction of certain mysids to stimulation by light and gravity. *J. Mar. Biol. Assoc.*, **24**: 89–97.

Fraenkel, G., 1931. Die Mechanik der Orientierung der Tiere in Raum. *Biol. Rev.*, **6**: 36–87.

Franz, V., 1911. Phototaktische lokomotions perioden bei *Hemimysis*. *Int. Rev. Hydrobiol. (Biol. Suppl.)*, **3**: 1–23.

Graham, C. H., and H. K. Hartline, 1935. The response of single visual sense cells to lights of different wave lengths. *J. Gen. Physiol.*, **18**: 917–931.

Haig, Charles J., 1941. The course of rod dark adaptation as influenced by the intensity and duration of pre-adaptation to light. *J. Gen. Physiol.*, **24**: 735–751.

Hartline, H. Keffer, 1930. The dark adaptation of the eye of *Limulus*, as manifested by its electric response to illumination. *J. Gen. Physiol.*, **13**: 379–389.

Hartline, H. K., and P. Robb McDonald, 1947. Light and dark adaptation of single photoreceptor elements in the eye of *Limulus*. *J. Cell. Comp. Physiol.*, **30**: 225–254.

Hecht, Selig, 1919. Sensory equilibrium and dark adaptation in *Mya arenaria*. *J. Gen. Physiol.*, **1**: 545–558.

Hecht, Selig, 1920. Intensity and the process of photoreception. *J. Gen. Physiol.*, **2**: 337–347.

Hecht, Selig, 1921. The relation between the wave length of light and its effect on the photosensory process. *J. Gen. Physiol.*, **3**: 375–390.

Hess, C., 1910. Neue Untersuchungen über den Lichtsinn bei wirbellosen Tieren. *Pflueger's Arch.*, **136**: 282–367.

Jahn, T. L., 1946. The electroretinogram as a measure of wave-length sensitivity to light. *J. New York Ent. Soc.*, **54**: 1–8.

Jahn, T. L., and V. J. Wulff, 1948. The spectral sensitivity of *Dytiscus fasciventris*. *J. New York Ent. Soc.*, **56**: 109–117.

Johnson, W. H., 1938. The effect of light on the vertical movements of *Acartia clausii* (Giesbrecht). *Biol. Bull.*, **75**: 106–118.

Keeble, F. W., and F. W. Gamble, 1904. The colour-physiology of higher crustaceans. *Phil. Trans. Roy. Soc. London, Ser. B*, **196**: 295–388.

Larkin, P. A., 1948. *Pontoporeia* and *Mysis* in Athabaska, Great Bear and Great Slave Lakes. Bull. Fish. Res. Bd. Can., No. 78, 33 pp.

Loeb, J., 1918. Forced Movements, Tropisms, and Animal Conduct. J. B. Lippincott, Philadelphia, 209 pp.

Lucas, C. E., 1936. On certain inter-relations between phytoplankton and zooplankton under experimental conditions. *J. du Conseil,* **11**: 343–362.

Mast, S. O., 1917. The relation between spectral color and stimulation in lower organisms. *J. Exp. Zool.,* **22**: 471–528.

Menke, H., 1911. Periodische Bewegungen und ihr Zusammenhang mit Licht und Stoffwechsel. *Pflueger's Arch.,* **140**: 39–91.

Moore, A. R., 1912. Concerning negative phototropism in *Daphnia pulex*. *J. Exp. Zool.,* **13**: 573–575.

von Buddenbrock, W., 1914. Über die Orientierung der Krebs in Raum. *Zool. Jahrb., Abt. Allg. Zool., Physiol.,* **34**: 479–514.

Weiss, Harry B., 1943. The group behavior of 14,000 insects to colors. *Ent. News,* **54**: 152–156.

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BOARFISHES OF THE GENUS ANTIGONIA OF THE WESTERN ATLANTIC

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BOARFISHES OF THE GENUS *ANTIGONIA* OF THE WESTERN ATLANTIC [1]

FREDERICK H. BERRY [2]

SYNOPSIS: The recently named boarfish *Antigonia combatia* Berry and Rathjen from the western Atlantic and the deeper-bodied *Antigonia capros* Lowe from the western Atlantic and the Indo-Pacific are described, illustrated, and compared with other nominal forms from the Indo-Pacific. Appreciable individual and geographic variation characterizes *Antigonia combatia* and apparently also exists in *Antigonia capros*. The boarfishes range in the western Atlantic from off southern Brazil to off the northern Atlantic coast of the United States, in water approximately 37 to 325 fathoms deep.

INTRODUCTION

The data developed on the biology and taxonomy of the genus *Antigonia* during an analysis of the relationships of *Antigonia combatia* Berry and Rathjen (1959) comprise the basis of this study.

Specimens of *Antigonia* previously were rare in most museum collections, but the recent work in the western North Atlantic by the U. S. Fish and Wildlife Service vessels OREGON, COMBAT, SILVER BAY, and THEODORE N. GILL has produced series of specimens that add appreciably to the knowledge of this group.

The boarfish genus *Antigonia* is known from tropical and subtropical waters of the Gulf of Mexico and the Caribbean Sea, the western and eastern Atlantic Ocean, the Indian Ocean, and the western Pacific eastward to Hawaii. It has not been reported from the eastern Pacific off the American continents. Specimens are usually taken in waters of about 37 to 325 fathoms, but the larvae apparently are near-surface pelagic forms. Of the 13 nominal species that have been ascribed to this genus or its synonyms, 5 appear to be valid species: *Antigonia capros* Lowe, *Hypsinotus rubescens* Günther, *Antigonia eos* Gilbert, *Antigonia malayanus* Weber, and *Antigonia combatia*. Four others are synonyms, *Caprophonus aurora* Müller and Troschel (= *A. capros*), *Antigonia steindachneri* Jordan and Fowler (= *A. capros*), *Antigonia fowleri* Franz (= *A. rubescens*), and *Anti-*

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[1] Contribution No. 27 of the U. S. Fish and Wildlife Service Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia.

[2] The author is a Fishery Research Biologist of the U. S. Fish and Wildlife Service at the South Atlantic Fishery Investigations (Bureau of Commercial Fisheries Biological Laboratory), Brunswick, Georgia. Manuscript submitted 14 July 1958.

gonia browni Fowler (= *A. capros*). Of the four remaining, the relationships of *Antigonia rubicunda* Ogilby and *Antigonia rhomboidea* McCulloch are uncertain, *Hypsinotus benhatatate* Bleeker is a *nomen nudum,* and *Antigonia mulleri* Klunzinger is of the family Zeidae.

Two species of boarfish occur in the western Atlantic: the deep-bodied *Antigonia capros,* with body depth generally greater than standard length, known also from eastern Atlantic and Indo-Pacific waters; and the recently described *Antigonia combatia,* a shallower-bodied species known only from the western Atlantic.

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Collection Abbreviations

ANSP—Academy of Natural Sciences of Philadelphia
BBL—Bears Bluff Laboratories
BMNH—British Museum (Natural History)
CNHM—Chicago Natural History Museum
CU—Cornell University
GCRL—Gulf Coast Research Laboratory
MCZ—Museum of Comparative Zoology
MMF—Museu Municipal do Funchal, Madeira
MNRJ—Museu Nacional (Rio de Janeiro)
NAFI—North Atlantic Fishery Investigations (U. S. Fish and Wildlife Service)

SAFI—South Atlantic Fishery Investigations (U. S. Fish and Wildlife Service)
SU—Stanford Natural History Museum
TU—Tulane University
UF—University of Florida
UMML—University of Miami Marine Laboratory
USNM—U. S. National Museum

Definitions and Methods

Standard length (S.L.)—from tip of snout to middle of end of caudal base (hypural bones). All body lengths given are standard length unless otherwise specified.

Total length (T.L.)—from tip of snout to vertical of longest caudal ray.

Body depth—from origin of pelvic spine to origin of 2nd dorsal spine.

Snout to 1st dorsal origin—from tip of snout to origin of 1st spine of dorsal fin.

Snout to pectoral—from tip of snout to origin of spine of pectoral fin.

Snout to pelvic—from tip of snout to origin of spine of pelvic fin.

Snout to 1st anal spine—from tip of snout to origin of 1st spine of anal fin.

Peduncle depth—vertical depth at end of caudal base.

Anal base length—from origin of 1st anal spine to origin of last anal softray.

Third dorsal spine length—from origin to tip of 3rd spine of dorsal fin.

First anal spine length—from origin to tip of 1st spine of anal fin.

Pectoral length—from origin of pectoral spine to tip of longest pectoral softray with fin in normal position against body.

Pelvic spine length—from origin to tip of pelvic spine.

Head length—greatest distance from tip of snout to fleshy margin of operculum.

Eye diameter—greatest horizontal diameter between circumorbitals.

Snout length—least distance from tip of snout to inner margin of anterior circumorbitals.

Upper jaw length—from anteriomedian tip of upper lip (premaxillary junction) to anterioventral angle of upper jaw (maxillary).

Dorsal fin counts—the fin consists of spines continuous with softrays.

Anal fin counts—the fin consists of spines continuous with softrays.

Branching of dorsal and anal softrays—frequently the terminal softray in the dorsal and anal fins is branched several times below the scaly sheath, and the next to last softray may be in close proximity to the last, making an accurate count difficult.

Pectoral fin counts—the fin consists of a spine at the fin origin and softrays. Counts were made on both pectoral fins of each fish because slight bilateral variations exist.

Pelvic fin counts—the fin consists of a spine and branched softrays.

Caudal fin counts—the fin consists of 4 dorsal secondary rays, one unbranched and 5 branched dorsal principal rays, 5 branched and one unbranched ventral principal rays, and 3 ventral secondary rays. The principal rays originate on the hypural bones; the secondary rays do not. Counts of secondary rays were made on only a few specimens that were cleared and stained with alizarine.

Branchiostegal counts—branchiostegal rays were counted on each side of only a few cleared and stained specimens.

Gillraker counts—upper limb and lower limb gillrakers were counted on the first arch.

Scale counts—the number of diagonal scale rows from the junction of the operculum and shoulder girdle to the caudal base were counted. This count was begun at the operculum-shoulder girdle junction, progressing posteriorly to about the tip of the pectoral fin (in normal position against body); the last row as counted above was traced ventrally to a level with the straight part of the lateral line on the caudal peduncle, and the count was continued to the caudal base. Because of incomplete diagonal rows and intervening rows, the counts made are considered to have an accuracy of $\pm$ 1 scale. Counts of scales along the lateral line were not recorded because most of the scales along the curved portion of the lateral line do not have pores and do not cross the lateral line, but group about it dorsally and ventrally. In sample comparisons, from about 3 to 10 more scales were counted along the lateral line of a fish than were recorded for the scale row count.

KEY TO THE SPECIES OF *Antigonia* OF THE ATLANTIC OCEAN [3]

A. Dorsal spines 9 (rarely 10); dorsal softrays 26 to 30; anal softrays 23 to 28; pectoral rays I-12 (rarely I-11 or I-13); body depth from about 15 to 70 mm. S.L. 64 to 100% S.L., above 70 mm. S.L. 62 to 85% S.L.; pelvic spine length 12 to 23% S.L. ..... *Antigonia combatia* Berry and Rathjen

AA. Dorsal spines 8 (rarely 7 or 9); dorsal softrays 31 to 37; anal softrays 29 to 34; pectoral rays I-13 (rarely I-12 or I-14); body depth from about 15 to 70 mm. S.L. 120 to 136% S.L., above 70 mm. S.L. 98 to 127% S.L.; pelvic spine length 24 to 38% S.L. ..... *Antigonia capros* Lowe

Antigonia combatia Berry and Rathjen
(Figures 1, 3, 10)

Antigonia capros (*non* Lowe), Longley and Hildebrand, 1941, p. 147 (in part; Tortugas, Florida).—Springer and Bullis, 1956, p. 89 (in part; OREGON Sta. 32, 29°10′ N., 85°55′ W., Sta. 1026, 25°08′ N., 84°19′ W., and Sta. 1343, 22°59′ N., 79°17′ W.).

Antigonia browni (*non* Fowler), Fowler, 1952, p. 4 (off Boynton Beach, south of Sombrero Key Light, and southeast of Sand Key Light, Florida). —Briggs, 1958, p. 271 (in part; based on Fowler, 1952, p. 4; southern Florida).

SYNONYMY: It is probable that in their description of *A. capros* from Tortugas, Longley and Hildebrand (1941: 147) considered two specimens of *A. combatia*, USNM 171784 and USNM 116755, collected by W. H. Longley from south of Tortugas, Florida, and bearing the identity label of *A. capros*. The three paratypes of *A. combatia* that Fowler (1952: 4) identified as *A. browni* from off southern Florida are cataloged as ANSP 74840, ANSP 75409, and ANSP 75410.

DIAGNOSIS: [4] An *Antigonia* with dorsal spines 9 (rarely 10), dorsal softrays 29 (26 to 30), anal softrays 27 (23 to 28), pectoral I-12 (rarely I-11 or I-13), scale rows 53 (about 49 to 57), body depth 66.7 (100.8 to 62.4), third (longest) dorsal spine length 16.2 (30.2 to 16.2), first (longest) anal spine length 7.7 (16.2 to 7.7), pelvic spine length 12.4 (22.6 to 12.4), upper jaw length 9.0 (8.1 to 11.1).

DESCRIPTION: Counts and measurements are given in tables 1, 2, and 3. Body compressed and elevated. Greatest vertical body depth (from base of 2nd spine of dorsal fin to pelvic spine origin)

[3] Nominal species of Indo-Pacific distribution are not keyed because of their uncertain relationships. They are distinguished in the sections on relationships.

[4] The number after each character is the value recorded for the holotype. Numbers in parentheses following this are ranges in values of all specimens. Where the proportion decreases with growth, the larger extreme of the range is placed first. Body proportions are in percent of standard length (% S.L.). This procedure is followed in the Description.

66.7 (100.8-62.4), decreasing in proportion to S.L. with growth (fig. 4). Greatest body width (near lateral midline of body at cleithrum) 19.7 (value of holotype only). Snout to 1st dorsal spine 50.0 (69.4-50.0), decreasing in proportion to S.L. with growth. Snout to pectoral origin 38.0 (46.8-36.4), decreasing in proportion to S.L. with growth. Snout to pelvic origin 57.7 (73.5-54.9), decreasing in proportion to S.L. with growth. Snout to 1st anal spine 68.8 (84.5-66.7), decreasing in proportion to S.L. with growth. Caudal peduncle deeper than long, its depth at caudal base 12.0 (16.2-11.9), decreasing in proportion to S.L. with growth. Lateral line curving upward to below about 4th dorsal spine, then curving downward approximating the dorsal body contour posteriad to midline of body below the dorsal softrays, extending past the caudal base, and ending immediately anterior to the termination of the scaly covering of the caudal ray bases.

Figure 1. *Antigonia combatia*, holotype, USNM 159597, 117 mm. in standard length, COMBAT Sta. 259, 24°29′ N., 83°28′ W., southwest of Tortugas, Florida.

Head length 34.2 (43.4-34.2), decreasing in proportion to S.L. with growth. Profile changing with growth (fig. 3); an apex produced by upper end of supraoccipital crest with concavities between apex

and dorsal origin (fig. 3: F, K, P, Q) and between apex and snout (fig. 3: E, T, and others); these concavities varying with growth stage and individuals (fig. 3: B, J). Snout length 10.3 (12.5-9.9), decreasing only slightly in proportion to S.L. with growth. Cleft of mouth angular. Lower jaw slightly projecting. Upper jaw length (fig. 7) 9.0 (8.1-11.1), growing nearly in direct proportion to S.L. Eye diameter 13.2 (20.4-13.2), decreasing in proportion to S.L. with growth. Bony interorbital width 10.4 (value of holotype only). Denticulated ridges, about 12 to 15 in a definite pattern on head above eye, curving anteriad to posteriad. Denticulated ridges on snout below and in front of eye, on preopercle and subopercle.

Teeth small and conical in a narrow band in front and partially around the side of each jaw. No teeth on vomer, palatines, or tongue.

Gillrakers moderate, 5 (3-5) + 16 (14-16). Branchiostegals 6.

Dorsal spines 9 (9-10) (table 1). One specimen with 10 spines, cleared and stained, 65.5 mm. S.L., has 10th spine and 1st softray articulating with same interneural spine, while other stained specimens with 9 spines have separate interneural spines for the 9th spine and the 1st softray. One specimen with 9 spines has the 7th spine split to about three-fourths the distance from the tip, forming two points. Third spine the longest 16.2 (30.2-16.2), generally decreasing in proportion to S.L. with growth; 1st spine the shortest; 2nd spine the next to the shortest in length; and the 3rd through the last spine in a graduated series decreasing in length posteriad. First and second dorsal fins continuous, shallowly notched at connection.

Anal spines 3 (3). One aberrant specimen, 66 mm. S.L., has elements of all 3 spines fused into one spine mass. First spine the longest 7.7 (16.2-7.7), generally decreasing in proportion to S.L. with growth; the 2nd and 3rd spines successively shorter. Third spine and 1st softray connected by a shallow notched membrane.

Dorsal softrays 29 (26 to 30). Anal softrays 27 (23 to 28) (table 2). In both fins the 2nd softray is the longest; the 1st softray is unbranched in smaller specimens and is slightly branched in some larger specimens, the last softray is frequently branched 6 or 7 times to the scaly sheath in specimens of all sizes, and the other softrays are moderately branched in specimens of all sizes (softrays broken in many specimens). Proximal portion of the softrays covered by a fleshy, scale-covered sheath. Anal fin base length 44.4 (55.2-40.7), decreasing in proportion to S.L. with growth.

Caudal fin subtruncate. Caudal principal rays 6 + 6 (in all specimens); the most dorsal ray and the most ventral ray are unbranched.

TABLE 1

RELATION OF NUMBER OF DORSAL SPINES TO NUMBERS OF PECTORAL SOFTRAYS FOR *Antigonia combatia* (179 SPECIMENS) AND *Antigonia capros* (103 SPECIMENS). PECTORAL SOFTRAY COUNTS ARE FROM BOTH SIDES OF EACH FISH, AND THE SINGLE SPINE ON EACH SIDE IS NOT INCLUDED IN THIS COUNT. NUMBER OF SPECIMENS WITH EACH COMBINATION IN PARENTHESES.

DORSAL SPINES	PECTORAL SOFTRAYS (Spine of each fin excluded from count)				
	11 - 12	12 - 12	12 - 13	13 - 13	13 - 14
VII				capros (1)	
VIII			capros (3)	capros (93)	capros (3)
IX	combatia (1)	combatia (161)	combatia (11)	capros (3) combatia (3)	
X		combatia (1)	combatia (1)	combatia (1)	

AND 97 SPECIMENS OF *Antigonia capros* (cap). NUMBERS ARE THE COUNTS OBTAINED FOR EACH COMBINATION.

ANAL SOFTRAYS	DORSAL SOFTRAYS											
	26	27	28	29	30	31	32	33	34	35	36	37
23	—	—	com	—	—	—	—	—	—	—	—	—
	—	—	1	—	—	—	—	—	—	—	—	—
24	—	com	com	—	—	—	—	—	—	—	—	—
	—	1	1	—	—	—	—	—	—	—	—	—
25	com	com	com	com	—	—	—	—	—	—	—	—
	2	11	12	2	—	—	—	—	—	—	—	—
26	com	com	com	com	com	—	—	—	—	—	—	—
	1	14	57	25	2	—	—	—	—	—	—	—
27	—	—	com	com	com	—	—	—	—	—	—	—
	—	—	10	32	5	—	—	—	—	—	—	—
28	—	—	—	—	com	—	—	—	—	—	—	—
	—	—	—	—	1	—	—	—	—	—	—	—
29	—	—	—	—	—	cap	—	cap	cap	—	—	—
	—	—	—	—	—	1	—	1	2	—	—	—
30	—	—	—	—	—	—	cap	cap	cap	—	—	—
	—	—	—	—	—	—	4	6	4	—	—	—
31	—	—	—	—	—	—	cap	cap	cap	—	—	—
	—	—	—	—	—	—	2	15	18	—	—	—
32	—	—	—	—	—	—	cap	cap	cap	cap	—	cap
	—	—	—	—	—	—	2	9	18	5	—	1
33	—	—	—	—	—	—	—	—	cap	cap	cap	—
	—	—	—	—	—	—	—	—	6	1	1	—
34	—	—	—	—	—	—	—	—	cap	—	—	—
	—	—	—	—	—	—	—	—	1	—	—	—

TABLE 3

RANGES OF MEASUREMENTS OF BODY AND FIN PARTS (IN PERCENT OF STANDARD LENGTH) FOR DESCRIBED SIZES OR SIZE RANGES OF *Antigonia combatia* AND *A. capros*

Species	Locality	No.	Standard Length	Body Depth	Snout to 1st Dorsal	Snout to Pectoral	Snout to Pelvic	Snout to 1st Anal	Peduncle Depth	Anal Base
Antigonia combatia	Atlantic & Gulf U. S.	18	100–118	63.6– 73.5	50.0–54.0	37.7–39.7	56.1–62.3	68.2–77.9	11.9–13.2	40.7–46.6
		11	79–99	66.7– 79.7	50.3–56.0	36.4–41.1	54.9–64.1	68.2–77.8	12.0–13.6	42.5–50.0
		1	62	87.1	57.3	40.3	66.1	75.8		51.6
		9	31–45.5	89.6–100.6	61.3–69.4	40.6–45.1	62.7–73.5	75.2–84.5	14.0–15.5	50.6–55.2
		2	23.5–26	92.3–100.8	63.5–68.5	45.0–46.8	69.2–70.2	82.7–83.0	15.8–16.2	49.6–52.3
	Cuba	1	100	85.0	57.0	42.0	66.0	76.5	14.0	48.0
	Honduras & Nicaragua	2	60.5–65	86.0– 90.8	56.7–60.0	41.3–41.5	63.6–66.9	75.2–78.5	13.8–14.0	51.2–54.3
		4	40.5–42	84.5– 91.6	60.0–62.7	40.5–41.0	61.9–66.7	72.6–76.5	13.6–15.4	49.4–50.6
	British Guiana	6	69–84.5	75.4– 85.1	51.4–56.3	39.7–41.5	61.9–63.8	71.0–75.2	12.6–13.5	46.8–51.1
		2	57–60	85.1– 89.2	55.3–56.7	40.8–41.2	63.2–66.7	74.2–75.8	13.5–13.7	50.9–53.3
	Surinam	32	61–83	62.4– 77.2	50.3–55.9	37.0–43.6	56.4–69.7	66.7–75.5	11.7–13.3	41.3–47.9
		9	51–59.5	78.2– 81.7	53.6–58.5	40.2–44.2	62.6–69.2	72.2–78.3	12.6–14.2	47.0–50.9
		2	39.2–44.5	87.6– 94.4	58.4–60.7	42.7–43.6	67.4–68.9	76.4–79.1	13.5–14.3	51.7–53.6
	Brazil	3	69–81	64.8– 73.8	50.6–52.3	37.7–39.7	55.6–57.6	67.9–70.9	11.9–12.5	42.1–43.5
		6	56–67.5	64.9– 75.2	51.1–54.6	38.8–42.7	57.3–65.0	67.2–74.4	12.1–13.0	42.0–44.7
		3	32–51.5	72.8– 92.2	51.5–62.8	38.8–44.4	59.2–68.8	68.9–75.6	13.6–14.7	44.7–51.3
Antigonia capros	Madeira	1	138	105.8	67.3	39.7	67.8	79.0	14.2	56.2
	Atlantic U. S.	3	109–127	105.5–122.2	60.9–67.6	37.4–39.8	71.5–78.7	79.7–88.4	13.8–15.3	55.9–63.9
		4	68.5–85	111.7–122.4	64.8–70.1	38.2–41.2	76.4–78.2	83.9–85.9	14.2–15.3	58.2–63.1
		5	50–65.5	118.7–134.3	66.7–77.2	40.4–42.0	78.1–82.9	85.1–91.1	13.6–15.8	63.6–66.7
		3	44.5–48	116.7–132.6	64.6–71.7	39.6–43.5	79.2–83.7	85.4–90.0	15.2–15.2	60.4–67.4
		1	26	129.2	75.0	44.2	81.9	86.5	16.9	69.2
	Gulf U. S.	19	110–134	98.3–108.7	59.6–65.0	37.4–40.9	69.3–74.8	76.4–83.5	13.9–15.8	52.5–61.0
		11	100–109	100.9–113.6	60.2–66.5	37.7–40.8	70.2–76.1	78.6–85.8	13.9–16.5	52.8–60.8
		16	69.5–97	108.5–126.6	62.7–71.2	36.2–41.3	71.2–79.1	78.0- 87.1	14.0–16.2	57.1–65.5
		3	52–58.5	117.1–127.9	68.4–70.3	40.5–45.2	77.8–83.7	86.3–91.3	15.0–16.2	60.7–65.4
		8	39–47.5	125.3–136.0	70.5–76.7	40.9–43.0	80.9–85.4	88.2–92.7	12.8–16.1	65.3–69.8
		3	25.5–29	125.9–132.1	72.4–74.7	43.1–43.9	81.0–86.0	87.9–92.5	16.2–16.9	64.5–65.1
	Honduras & Nicaragua	1	131	103.8	62.2	38.2	72.1	76.6	14.9	57.3
		4	76–88.5	110.2–121.7	65.5–68.5	37.8–41.3	72.9–78.3	81.4–86.2	13.4–15.8	61.0–64.5
		6	38–59	120.3–131.2	69.5–74.1	42.4–46.1	79.7–86.0	85.9–92.0	14.1–14.6	
	Surinam	2	45.5–57.5	120.0–124.2	70.3–70.4	42.4–43.5	78.3–80.9	85.2–86.8	13.6–14.6	61.2–63.7
		2	88.5–89	106.8–110.1	62.7–63.7	39.3–39.8	72.0–75.3	79.1–82.2	14.6–14.7	58.4–58.8

TABLE 3—Continued

Species	Standard Length	3rd Dorsal Spine	1st Anal Spine	Pectoral Length	Pelvic Spine	Head Length	Eye Diameter	Snout Length	Upper Jaw Length
Antigonia combatia	100–118	16.2–22.1	7.7–11.1	28.5–33.3	12.4–15.5	34.2–38.2	13.2–16.0	9.9–11.6	8.3– 9.8
	79–99	18.4–23.8	8.2–12.7	30.3–33.3	13.2–17.8	35.4–38.8	14.3–16.0	10.0–11.8	9.0– 9.7
	62	28.4	13.7	34.2	19.2	37.9	15.5	11.0	8.9
	31–45.5	25.7–28.1	12.7–16.2	33.7–38.7	15.9–22.6	38.4–41.9	14.9–17.8	10.5–12.5	8.4– 9.1
	23.4–26	25.0–29.4	11.9–12.8	38.8–40.4	16.5–19.6	41.9–43.4	18.5–20.4	11.5–12.3	8.1–10.2
	100	24.5	12.5	32.3	17.5	39.0	16.4	11.7	9.9
	60.5–65	27.3–30.2	14.0–16.2	33.8–34.0	18.2–20.6	37.1–37.4	16.2–16.9	10.8–11.7	9.8–10.2
	40.5–42	23.3–28.9	13.6–14.8	35.7–38.3	18.8–20.5	37.8–39.8	15.9–19.8	10.8–11.9	8.4–10.5
	69–84.5	21.9–23.9	13.0	32.3–34.5	16.8–18.4	37.6–39.3	15.5–17.8	10.6–11.9	9.6–10.6
	57–60	24.6	12.3–13.5	36.3	17.7–20.0	39.5–40.0	15.0–16.0	11.0–11.4	9.1– 9.8
	61–83	17.2–23.1	8.9–11.8	30.1–36.2	14.1–18.2	36.8–40.9	15.4–18.9	9.9–12.3	9.2–11.1
	51–59.5	22.3–26.5	11.5–13.8	31.9–35.8	17.3–20.2	37.4–40.4	15.9–16.5	10.1–11.8	9.2–10.0
	39.2–44.5	25.8–28.1	13.5–13.8	34.2–36.7	18.0–20.4	40.4–41.6	15.7–16.6	11.5–12.1	8.9– 9.9
	69–81	17.3–19.9	8.3–10.3	31.5–33.1	14.5–14.9	36.7–38.0	14.9–15.9	10.9–11.4	9.7–10.3
	56–67.5	18.9–23.1	9.2–12.0	33.0–36.8	14.0–16.4	37.1–40.2	15.9–17.9	11.1–12.4	10.0–11.1
	32–51.5	22.2–26.1	12.6–14.7	35.0–36.0	17.1–18.9	36.9–40.9	16.5–17.5	10.5–12.0	9.3– 9.5
Antigonia capros	138	26.4		31.4	28.0	37.3	16.9	11.0	8.7
	109–127	27.3–30.0	15.2–18.5	31.3–34.7	26.0–27.0	33.9–38.0	13.4–14.8	9.4–11.7	7.4– 9.1
	68.5–85	29.6–38.2	14.6–20.4	33.3–35.0	24.1–31.2	35.8–38.2	15.3–16.1	8.9–11.1	8.9– 9.5
	50–65.5	33.3–44.5	17.4–21.6	36.0–40.2	29.8–35.3	36.6–40.2	15.8–18.8	8.9–11.6	8.2– 9.6
	44.5–48	33.3	16.3–19.8	35.4–38.0	27.1–31.2	35.4–40.4	15.4–17.4	9.6–10.1	8.1– 8.9
	26		15.4	41.5	27.7	42.3	16.5	8.8	7.7
	110–134	23.3–30.0	14.1–16.7	31.1–36.6	24.8–28.7	33.9–39.2	13.4–16.4	8.8–11.7	7.4– 9.7
	100–109	25.7–29.8	14.2–16.6	31.5–37.5	26.5–28.4	35.3–37.6	14.4–15.6	9.4–10.7	8.1–10.0
	69.5–97	28.9–37.1	15.4–18.5	33.3–35.9	26.0–33.1	35.1–37.4	14.0–16.3	9.0–11.2	8.6– 9.9
	52–58.5	35.0	13.9–19.8	36.2–40.4	30.8–35.1	37.8–38.5	16.2–18.3	10.5–10.9	8.1– 9.2
	39–47.5	35.5–43.0	16.8–20.9	35.8–40.0	32.6–37.2	36.4–40.7	15.9–17.9	9.8–11.6	7.3– 9.6
	25.5–29	33.2	15.5–17.6	38.6–39.2	30.2–30.6	37.9–41.2	17.0–17.3	9.8–10.7	7.5– 7.9
	131		16.0	34.4	26.0	35.1	13.7	10.5	8.8
	76–88.5	27.7–36.2	16.6–20.5	35.6–38.0	28.2–34.9	36.6–38.2	14.9–16.6	9.7–10.3	9.0– 9.9
	38–59	35.6–36.5	17.5–19.1	38.6–43.5	29.7–32.9	39.0–42.1	17.1–20.2	9.5–11.1	9.1–10.2
	45.5–57.5	38.3	18.3–18.7	37.4–39.6	36.0	37.9–44.0	17.6–19.1	9.9–10.3	8.8–10.4
	88.5–89	29.5–31.5		34.5–35.4	27.1–29.9	34.5–35.6	15.4–15.5	10.1–10.4	8.5– 9.0

others branched. Caudal secondary rays 4 + 3 (in seven cleared and stained specimens). Continuation of fleshy part of body extending posteriad over bases of caudal rays covered by about 5 vertical rows of scales.

Pectoral fin bluntly pointed. Pectoral rays I-12 (rarely I-11 or I-13) (table 1). Length of pectoral spine decreasing in proportion to length of pectoral softrays with growth. First softray unbranched, others branched. Pectoral length 29.1 (40.4-28.5), decreasing in proportion to S.L. with growth. Third or fourth softray the longest. Inserted in advance of a vertical to 1st dorsal fin origin.

Pelvic fin pointed. Pelvic rays I-5 (in all specimens), 5th softray rudimentary in one small specimen, rays connected by a membrane, membrane connects 5th softray to body. Pelvic spine length 12.4 (22.6-12.4), decreasing in proportion to S.L. with growth (fig. 5). First softray the longest element of the fin. Inserted below 1st dorsal fin.

Scale rows 53 (about 49 to 57). Body completely scaled except for small bony area immediately above pectoral origin. Scales cover mandibles (exposed portion), cheeks, throat, opercle; few scales on interopercle and subopercle and on and above snout. Scale rows, usually single, extend along each (lateral) side of the spines of the dorsal, anal, pectoral, and pelvic fins, and on the softrays of the pelvic fin. Several scale rows extend distally on the membranes between the softrays of the pectoral and caudal fins.

Most body scales have on exposed portion an elevated ridge that is bent posteriorly, aligned dorsoventrally, and denticulated on the distal margin. Most body scales also have, arising from scale base and with same alignment as the longer ridge, about 2 to 20 flattened ridgelike structures bearing from 1 to 4 points or denticles (fig. 2). Scales immediately below the dorsal softrays and on lower portion of the peduncle tend to lack the smaller ridgelike structures, and the number of these structures apparently increases with growth. Scales on bones of head have ridges aligned dorsoventrally along central part of scale, those on body with ridges on posterior portion of scale. Group of scales posterior to horizontally curving denticulated ridges above the eye have a centrally located crescentic ridge. On most body scales circuli originate at base of the dorsoventral ridge and align with contour of anterior field of the scale. Radii occur on imbedded portion (fig. 2).

Pigmentation essentially faded out on preserved specimens. A light orange area at the dorsal and anal fin bases over the position of the interneurals and interhemals, and a narow orange stripe sloping from the operculum-shoulder girdle junction to the midline of the

body at the caudal peduncle are visible on many of the specimens in formalin. A Kodachrome slide (35 mm.) taken of several specimens immediately after capture at Oregon Sta. 2013 shows the dorsal aspects of the head and body to be reddish pink blending into pink on the sides and then into silver on the ventrolateral aspects.

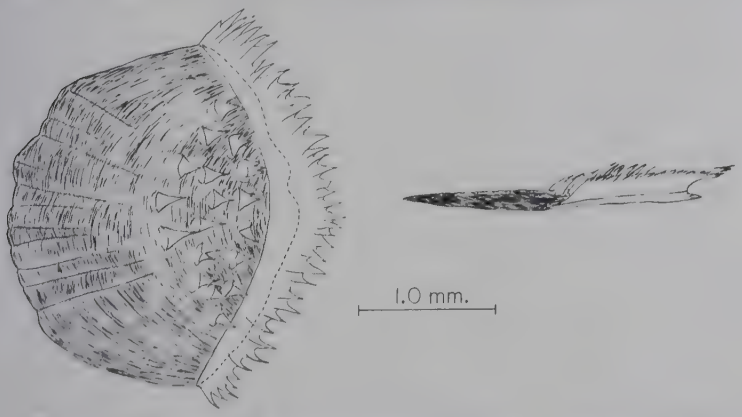

Figure 2. Top and side views of scale of holotype of *Antigonia combatia*, taken from below lateral line under second dorsal fin. Line of dashes on top view represents the posterior extension of the scale base, lying beneath the elevated dorsoventral ridge.

Gonads were developed in specimens from five collections. (1) Off Tortugas, Florida, Combat Sta. 259, 7 March 1957: 1 male (107 mm., with flacid testes that may have been partially spent); 2 females (111 and 117 mm., with well developed ovaries containing enlarged eggs). (2) West of Tortugas, Florida, Oregon Sta. 1026, 19 April 1954, 29 specimens: 2 with gonads not developed (38.5 and 39.5 mm.); 10 males (62 to 111 mm., mean size 91.2 mm.; smallest with slightly developed testes, others from 80 to 111 mm. with well developed testes); 17 females (79 to 118 mm., mean size 102.4 mm.; all with enlarged eggs in ovaries). (3) Off northern Cuba, Oregon Sta. 1343, 16 July 1955: 1 female (100 mm., with ovaries smaller than previously listed females and containing moderately developed eggs). (4) Off Surinam, Oregon Sta. 2013, 8 November 1957, of 107 specimens: 2 with gonads not developed (39.2 and 44.5 mm.); 58 males (51 to 75.5 mm., mean size 65.9 mm.; testes very enlarged in specimens larger than 65 mm.); 47 females (52 to 83 mm., mean size 68.8 mm.; specimens 55 mm. and smaller with small ovaries containing small eggs, specimens 55.5 mm. and larger with very large ovaries containing well developed eggs

and one of these appeared to be running-ripe). (5) Off Amazon River, Oregon Sta. 2066, 15 November 1957, 11 specimens: 2 with gonads not developed (37.5 and 51.5 mm.); 3 males with slightly developed testes (56, 58.5, and 64 mm.); 2 males with well developed testes (65.5 and 67.5 mm.); 4 females with well developed ovaries (66, 69, 75.5, and 81 mm.). Although Weber and de Beaufort (1929: 267) stated that males of *A. malayanus* had longer pelvic fins than the females, I found no such discrete differences attributable to sexual dimorphism in *A. combatia*. Of the specimens from Oregon Sta. 1026, the males tended to have shorter pelvic spines and a lesser body depth than the females, but the values were decidedly overlapping.

The smallest paratype, estimated at about 19 mm. S.L., from the stomach of a *Thunnus atlanticus* (Lesson), has the tail and peduncle and most of the fin rays missing. Its body depth (19.1 mm.), 1st anal spine length (2.4 mm.), pelvic spine length (3.4 mm.), and other body measurements identify it as continuous with the *A. combatia* series and as distinct from small *A. capros*. This specimen was identified as *A. capros* in Anderson and Gehringer (1957: 53).

Distribution: *Antigonia combatia* is recorded from off Brazil (Amazon River), Surinam, British Guiana, Caribbean Nicaragua and Honduras, the Leeward Islands, northern Cuba, Florida, North Carolina, and Massachusetts (fig. 8).

Development and Geographic Variation: The possibility that the specimens designated as paratypes of *A. combatia* may comprise two or more species was considered. The variations in body proportions and estimated relative growth of specimens from different localities suggested this, and the future acquisition of an adequate size series of specimens from other localized areas of the western Atlantic may demonstrate the description of *A. combatia* to be based in part on a yet undescribed species. However, the differences encountered in this series of specimens more probably are attributable to individual and geographic intraspecific variation.

The more conspicuous changes during growth of *A. combatia* are a depression of the body outline (decrease in body depth), and a proportional decrease in the lengths of the dorsal spines (principally the 3rd), the anal spines (principally the 1st), and the spine of the pelvic fins (compare F through J of fig. 3).

Table 3 shows that all of the body parts measured increase in size or length more slowly than the standard length. Therefore these body parts are proportionally smaller on large fish than on small fish. The proportional decrease of body depth to standard length with growth is apparent in figure 4.

Although the data available and the size range of specimens are incomplete, comparisons between collections from off Brazil (Amazon River), Surinam, British Guiana, Nicaragua, Honduras, Cuba, and the United States coast in the Gulf of Mexico and the Atlantic—each of progressively more northern latitude—indicate that the southern populations reach comparable stages in their allometric or heterogonic growth at smaller body sizes than the northern populations.

Specimens from off British Guiana, from the Caribbean, and from the Gulf and Atlantic off the United States seem to be closely related in this differential development, for specimens of similar size have generally similar body proportions. This group differs most from the specimens from off Surinam and Brazil, with the Brazilian specimens showing the most extreme divergence. Geographic variation is manifest in several body proportions, as may be seen in the relation of body depth to standard length in figure 4. At smaller sizes, estimated between 15 and 30 mm. S.L., specimens from the different localities apparently are directly comparable, so that measurements of both depth and standard length of a small specimen from off Brazil might be expected to equal both these measurements for a specimen of the same size from off the United States. However, at sizes larger than 30 or 40 mm. S.L., geographic variation is apparent in comparison of specimens of similar length. The more southern, Brazilian specimens average the least body depth. The Surinam specimens average a lesser depth than those from more northern localities. Specimens from British Guiana to the United States apparently average a more closely comparable depth-length relation (an incomplete series of specimens limits this interpretation), and have greater depths than specimens from Surinam and Brazil. The 100-mm. Cuban specimen (fig. 3: O) has a greater depth than specimens of similar length from the United States, but is generally similar in depth and other body proportions and in body outline to some smaller specimens from more southern localities, as to the 65-mm. Honduran specimen (fig. 3: N). The 82.5-mm. specimen from off Surinam has a slightly different head and body profile and less body depth (62.4% S.L.) than all other specimens, and it may represent the ultimate stage in the development of body outline (fig. 3: J). The northern populations probably attain greater lengths than those to the south.

Assessment of the relative positions of the coordinates of the groups of specimens in figure 4 suggests that the relative increase of body depth to standard length is heterogonic, and that a complete series of specimens from any locality might be described adequately by a curvilinear regression or by rectilinear regressions interrupted by at

least two growth inflections. Other body parts or measurements—snout to 1st dorsal spine, snout to 1st anal spine, snout to pelvic, 1st anal spine length, and 3rd dorsal spine length—are similar to body depth, both in showing a geographic difference in relative growth and in having a heterogonic growth pattern.

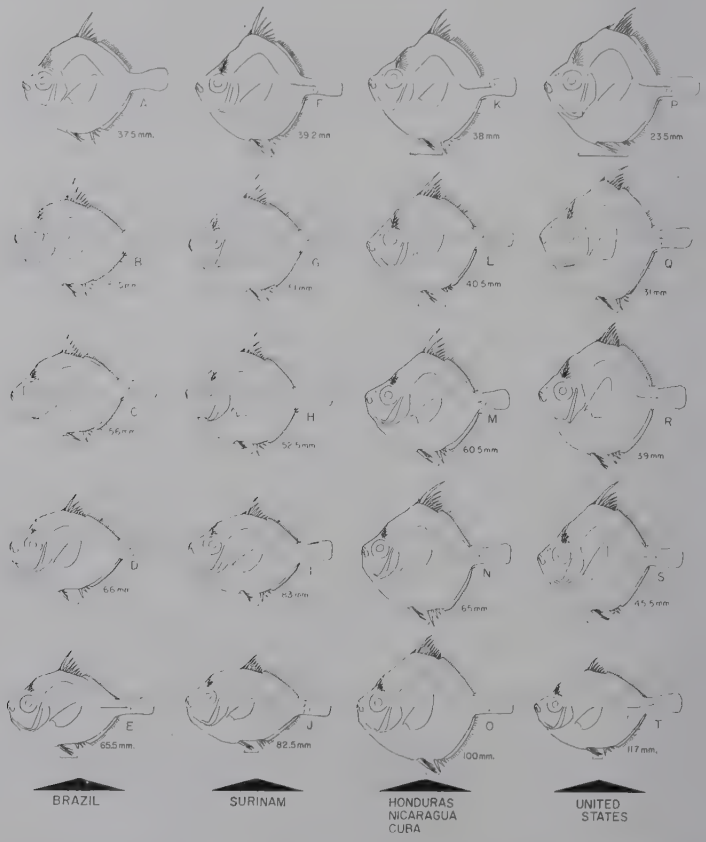

Figure 3. Body outlines of specimens of *Antigonia combatia* from five different areas, illustrating intraspecific changes occurring with growth and variation in outline, and interpopulation differences in degrees of development. Reference line under each outline represents 10 mm. Body length for each specimen is given in millimeters of standard length.

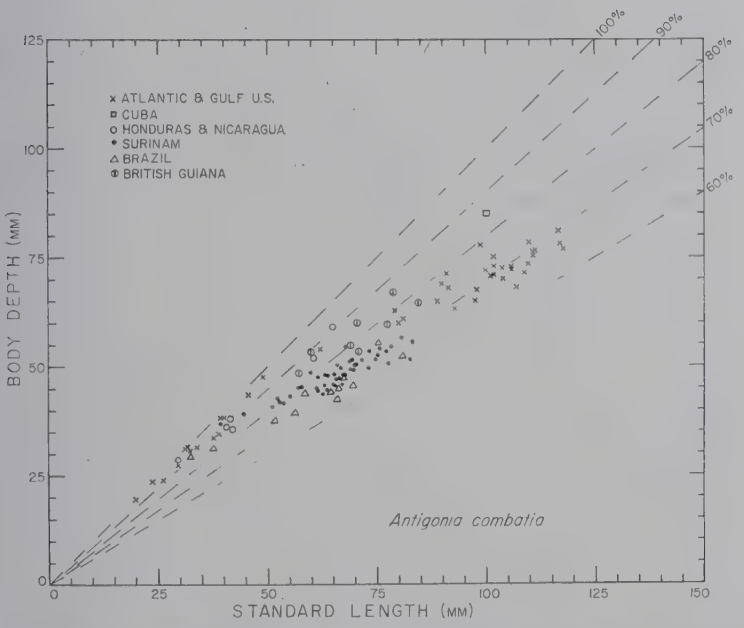

Figure 4. Relation of body depth to standard length for *Antigonia combatia* from five different areas. Reference lines of dashes represent proportional values; at "90%" body depth is 90% or nine-tenths of standard length.

The use of the term population in the above discussion refers to samples collected at designated separate localities. The specimens examined may be representatives of a continuous clinal population, but the sparsity of samples over the broad area considered fails to show any geographic centers of abundance or gaps in the species range. Hence, assigning subspecific designations to the collections from these discontinuous localities is not advisable.

Relationships: *Antigonia combatia* with dorsal softrays 30 or less and anal softrays 28 or less differs from *A. capros* Lowe (= *A. browni* Fowler = *Caprophonus aurora* Müller and Troschel = *A. steindachneri* Jordan and Fowler) and *A. eos* Gilbert in having fewer dorsal and anal softrays. *A. combatia* also differs from *A. capros* and *A. eos* in having a shallower depth of body and shorter 3rd dorsal, 1st anal, and pelvic spines.

Antigonia combatia is similar in numbers of dorsal and anal softrays to *A. rubescens* (Günther), *A. rubicunda* Ogilby, *A. malayanus*

Weber, *A. fowleri* Franz, and *A. rhomboidea* McCulloch. The five species are nominal forms of Indo-Pacific distribution and of uncertain relationships. Fraser-Brunner (1950) synonymized *A. mulleri* (questionably, possibly unidentifiable) and *A. malayanus* with *A. rubicunda;* and he synonymized *A. fowleri* and *A. rhomboidea* with *A. rubescens.* My examination of a larger series of specimens suggests modifications of his interpretations (discussed below). As the relationships of these

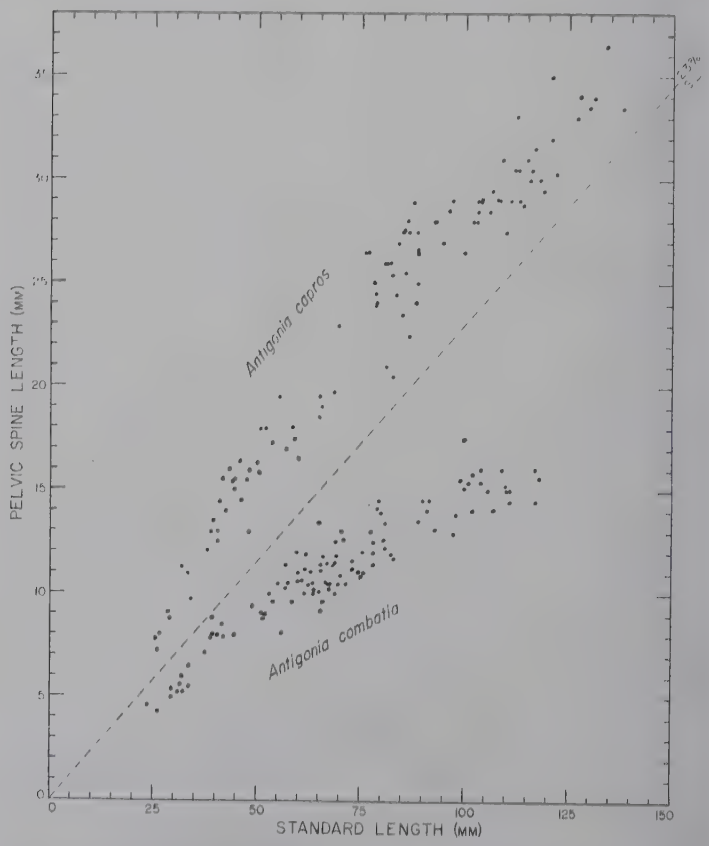

Figure 5. Relation of pelvic spine length to standard length for *Antigonia combatia* and *A. capros.* Reference line of dashes indicates values of pelvic spine length equivalent to 23% of standard length.

Indo-Pacific forms are not definite, it is best to distinguish *A. combatia* from the nominal species individually.

Antigonia rubescens was named *Hypsinotus* sp. by Temminck and Schlegel (1844: 84, pl. XLII, fig. 2) and described from a specimen about 4 inches in total length (which I estimate as about 80 mm. S.L.) from Japan, and the figure of the type is a natural size (1:1) reproduction. Compared to Temminck and Schlegel's figure of *A. rubescens*, *A. combatia* has a shallower body depth (107% S.L. in *A. rubescens*, 62.4 to 100.8% S.L. in all specimens of all sizes of *A. combatia*); a shorter 3rd dorsal spine (34% S.L. in *A. rubescens*, 16.2 to 30.2% S.L. in *A. combatia*); a shorter 1st anal spine (15.6% S.L. in *A. rubescens*, 7.7 to 14.8% S.L. in *A. combatia*); and a shorter pelvic spine (28% S.L. in *A. rubescens*, 12.4 to 22.6% S.L. in *A. combatia*).

The earliest redescription of *A. rubescens* was by Jordan and Fowler (1902: 523), and the larger specimen they illustrated appears to be conspecific (their fig. 2, USNM 50803, 119 mm. S.L.). However, their illustrated specimen has an open and extended mouth, and this probably prompted Fraser-Brunner (1950: 50) to describe *A. rubescens* as having, "Cleft of mouth small, nearly horizontal." The mouth is relatively small compared to certain specimens discussed below, but the cleft of the mouth is oblique and not nearly horizontal. Jordan and Fowler gave a scale count of "14-60-40" (the count of 60 apparently was made along the lateral line, as I counted approximately 58 and 61 scales along the lateral line for the two sides of the USNM specimen). This specimen has 44 and 45 scale rows, right and left sides, respectively, and the other 17 specimens I have identified as this species have about 38 to 47 scale rows. *A. combatia* differs from *A. rubescens* in having 49 to 57 scale rows.

A. combatia has a shorter pelvic spine than *A. rubescens* at comparable body sizes (from about 20 to 50 mm. S.L., 24 to 30% S.L. in *A. rubescens*, 14 to 23% S.L. in *A. combatia;* above 50 mm. S.L., 21 to 26% S.L. in *A. rubescens*, 12 to 20.9% S.L. in *A. combatia*). The 3rd dorsal spine of *A. combatia* averages a shorter length than that of *A. rubescens* (27 to 42% S.L. in *A. rubescens*, 16 to 30% S.L. in *A. combatia*); the 1st anal spine averages shorter (12.3 to 17.6% S.L. in *A. rubescens*, 7.7 to 16.2% S.L. in *A. combatia*); the pectoral fin above 50 mm. S.L. averages slightly longer (about 30 to 32% S.L. in *A. rubescens*, 28 to 36% S.L. in *A. combatia*). *A. combatia* has a shallower body depth at all comparable body lengths (84 to 106% S.L. in *A. rubescens*, 62 to 100.8% S.L. in *A. combatia*), a slightly shorter snout to 1st dorsal spine distance above 50 mm. S.L. (57 to 68%

S.L. in *A. rubescens,* 50 to 60% S.L. in *A. combatia*), and a longer upper jaw (8.0 to 9.5% S.L. in *A. rubescens*, 8.1 to 11.1% S.L. in *A. combatia*). The two species also show slight differences in profile (see figure 6). The figure of Temminck and Schlegel, or its outline, has been erroneously reproduced by Goode and Bean (1895, fig. 235), by Fowler (1936, fig. 381), and probably by Thompson (1943, fig. 524), to represent *A. capros.* Obviously the small first dorsal spine was omitted from Temminck and Schlegel's figure and its copies, and Boseman (1947: 84) stated that Burger's manuscript gave a count of 9 spines.

[Specimens of *A. rubescens* examined: USNM 50803 (1 specimen) 119 mm. S.L., Suruga Bay, Japan, Albatross Sta. 3720, 13 May 1900, 34 fathoms. USNM 50804 (6) 40 to 79 mm. S.L., Totmi Bay, Japan, Albatross. USNM 57588 (2) 77.5 and 79 mm. S.L., Yokohama, Japan. USNM 75465 (8) 26 to 60.5 mm. S.L., Mishai, Japan. USNM 135698 (2) 22 and 30 mm. S.L., Gulf of Tokyo, Japan, Albatross, 26 October 1906.]

Antigonia fowleri was described by Franz (1910: 58) apparently because he believed specimens he examined from Japan and the illustration and description by Jordan and Fowler (1902: 523, fig. 2) of *A. rubescens* were specifically distinct from Temminck and Schlegel's (1884: 84, pl. XLII, fig. 2) figure and description. He did not indicate adequate separations of the two forms, and because I consider Jordan and Fowler's specimens to be conspecific with *A. rubescens,* I also include *A. fowleri* as a synonym. As *A. fowleri* was based in part on Jordan and Fowler's description, *A. combatia* is considered to differ from *A. fowleri* in the same respects as it does from *A. rubescens.*

Antigonia rhomboidea, described and illustrated by McCulloch (1915: 111, pl. XVIII, fig. 1) from Victoria, Australia, may be identical to *A. rubescens.* McCulloch's figure, apparently a natural size (1:1) reproduction of a fish 115 mm. in total length (about 90 mm. S.L.), is similar in outline and proportions of body parts to Jordan and Fowler's figure and specimen of *A. rubescens* (1902: 523, fig. 2, USNM 50803), and is intermediate in body depth between this figure and Temminck and Schlegel's figure. One objection to this proposed synonymy is in scale counts. McCulloch stated that his specimen had "About fifty-eight scales between the operculum and the hypural." This description seems to imply that McCulloch counted scale rows rather than scales along the lateral line, and as specimens I have identified as *A. rubescens* have about 38 to 47 scale rows, a difference exists. Using values given for *A. rhomboidea* by McCulloch, *A. combatia* has a lesser body depth (1.03 in S.L. in *A. rhomboidea,* .99 to 1.60 in S.L. in *A. combatia*) and a shorter pelvic spine (1.4 in head length in

A. rhomboidea, 1.75 to 2.78 in head length in *A. combatia*). Based on my measurements of McCulloch's figure of *A. rhomboidea, A. combatia* has a lesser body depth (105.6% S. L. in *A. rhomboidea,* 62.4 to 100.8% S. L. in *A. combatia*), a shorter 1st anal spine (17.3% S.L. in *A. rhomboidea,* 7.7 to 14.8% S.L. in *A. combatia*), a shorter pelvic spine (26.4% S.L. in *A. rhomboidea,* 12.4 to 22.6% S.L. in *A. combatia*), a lesser snout to 1st dorsal spine distance (72.8% S.L. in *A. rhomboidea,* 50.0 to 68.5% S.L. in *A. combatia*).

Antigonia rubicunda was described by Ogilby (1910: 103) from Queensland, Australia, and was redescribed and illustrated by McCulloch (1915: 113, pl. XVIII, fig. 2). I have not seen Ogilby's description, but McCulloch (*loc. cit.*) stated that in Ogilby's (1910) description of his two type specimens, 62 and 65 mm. T.L. (about 48.5 and 52 mm. S.L.), "Ogilby has wrongly counted the number of spines and rays of the fins, while some of the proportions given by him are also incorrect." Using values given for *A. rubicunda* by McCulloch, *A. combatia* has more scales (45 rows in *A. rubicunda,* 49 to 57 rows in *A. combatia*), a shorter 3rd dorsal spine (1.06 into head length in *A. rubicunda,* 1.23 to 2.12 into head length in *A. combatia*), and a shorter pelvic spine (1.2 into head length in *A. rubicunda,* 1.75 to 2.78 into head length in *A. combatia*). Based on my measurements taken from McCulloch's figure of *A. rubicunda, A. combatia* has a shorter 3rd dorsal spine (34.0% S.L. in *A. rubicunda,* 16.2 to 30.2% S.L. in *A. combatia*), and a shorter pelvic spine (27.8% S.L. in *A. rubicunda,* 12.4 to 22.6% S.L. in *A. combatia*).

[A. rubicunda and *A. rhomboidea* may be synonymous. The difference in scale counts given by McCulloch (45 for *A. rubicunda,* 58 for *A. rhomboidea*) suggests a specific difference, however, and McCulloch's figure of *A. rubicunda* shows the upper jaw to be longer than that in his figure of *A. rhomboidea.* Fraser-Brunner's (1950: 721) interpretation of this last character is questioned because he synonymized *A. malayanus* Weber with *A. rubicunda*—and I regard *A. malayanus,* with a long upper jaw and a nearly vertical cleft of mouth, to be distinct from any other nominal species. I have been unable to identify two small specimens (BMNH 1912.11.28.63) from the Kai Islands which Fraser-Brunner designated as *A. rubicunda.* I have examined one of the specimens (33.3 mm. S.L.), and data on the other (33 mm. S.L.) have been kindly furnished by G. Palmer of the British Museum. The 33.3-mm. specimen has a longer upper jaw (12.8% S.L. in the Kai Islands specimen, 8.1 to 11.1% S.L. in *A. combatia*) than was found in specimens of *A. combatia.]*

Antigonia malayanus was described and figured by Weber (1913: 299, fig. 69) from the Arafura Sea, and was redescribed by Weber and de Beaufort (1929: 267, fig. 71). I have examined a 64.5-mm. specimen of *A. malayanus* (CNHM 52432) labeled "Cotype, *Siboga*

Figure 6. Top: *Antigonia rubescens*, 65.5 mm. S.L., USNM 50804. Middle: *Antigonia malayanus*, 67.5 mm. S.L., USNM 150996. Bottom: *Antigonia combatia*, 67.5 mm. S.L., SAFI, Oregon Sta. 2013.

253, Max Weber," and a 67.5-mm. specimen (USNM 150996) from Talogo Light, Philippine Islands, that is identical to the cotype and to Weber's description and figure. These specimens have upper jaw lengths of 12.5% S.L. (CNHM) and 13.9% S.L. (USNM), which values are greater than those of any other described species of *Antigonia* (figs. 6 and 7). Both specimens have 8 dorsal spines, which is the count Weber (1913: 299) gave for 14 specimens of 76 to 90 mm. T.L. (about 59 to 70 mm. S.L.). *A. malayanus* is similar to *A. combatia* in having a relatively short pelvic spine. *A. combatia* is distinct from *A. malayanus* in having normally 9 dorsal spines, a shorter upper jaw, and in alignment of the lower jaw (less protruded and less vertically cleft in *A. combatia*) (fig. 7). Herre and Herald (1951: 332) recorded this species from Luzon, Philippines, but gave no confirming description.

Antigonia mulleri was described by Klunzinger (1880: 380, pl. V, fig. 3) from two specimens of about 35 mm. T.L. from New Zealand. In appearance and known characters, *A. mulleri* belongs to the family Zeidae rather than Caproidae. Fraser-Brunner (1950: 722) placed it in questionable synonymy with *A. rubicunda,* but noted that this was uncertain because the shallow body and large mouth of *A. mulleri* were "more like that of a Cyttid."

Antigonia benhatatate (Bleeker) is apparently a *nomen nudum.* The earliest record I have been able to find for the specific name is in Bleeker's 1876 Systema Percarum Revisum (p. 310), where, with no description or figure, he gives, "*Hypsinotus* Sch. (1842 ?) = *Antigonia* Lowe (1843) = *Caprophonus* M. Tr. Sp. typ. *Hypsinotus benhatatate* Blkr." Bleeker's other reference to this name (1879: 9) is also by name only.

Holotype: USNM 159597, 117 mm. in standard length; taken at Station 259 of the M/V Combat in a flat trawl, presumably from the bottom, in water about 185 fathoms deep, 24°29′N., 83°28′W., about 30 miles WSW of Loggerhead Key, Tortugas, Florida, 7 March 1957.

Paratypes: USNM 159593 (1 specimen) 111 mm. S.L. (partially dessicated after original preservation), taken with the holotype. SAFI collection (1) 107 mm. S.L., taken with the holotype. MCZ 37604 (1) 49 mm. S.L., Capt. Bill II Sta. 83, 39°59′N., 69°32′W., about 40 miles southward of Nantucket Island, Massachusetts, 16 July 1952, 87-90 fathoms. SAFI collection (1) 37.5 mm. S.L., Combat Sta. 370, 35°05′ N., 75°09′W., about 17 miles ESE of Cape Hatteras, North Carolina, 16 June 1957, 100 fathoms. ANSP 75410 (2) 31 and 33.5 mm. S.L., off Boynton Beach, Palm Beach County, Florida, by A. R. Thompson

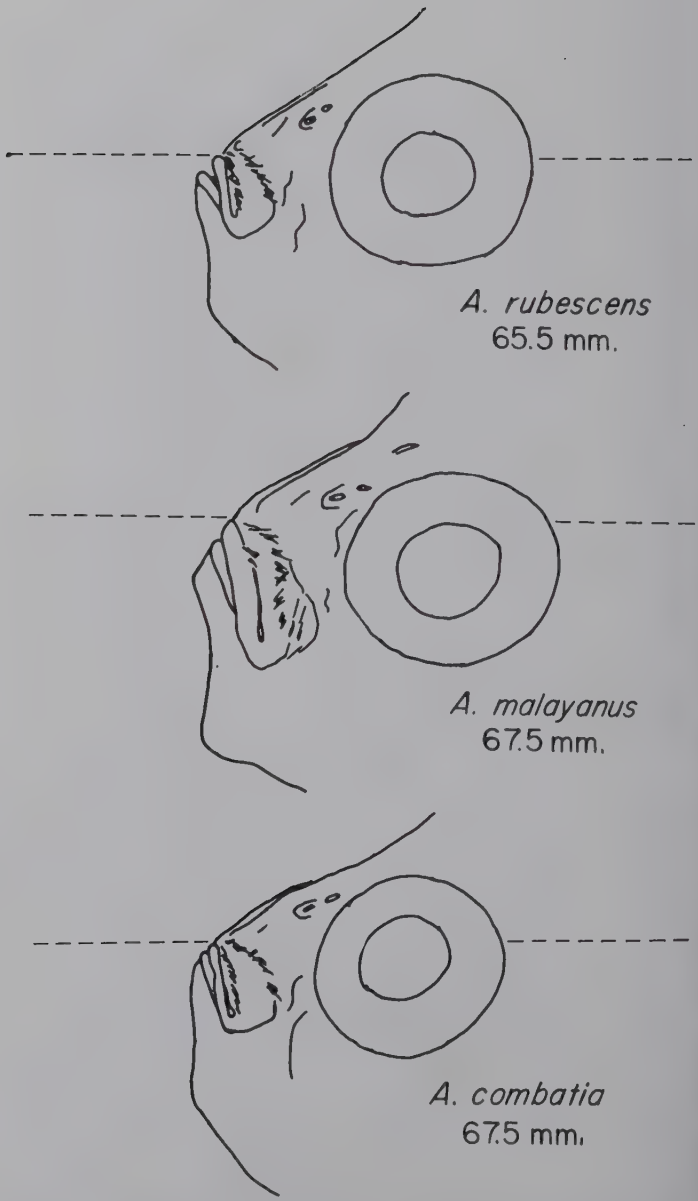

Figure 7. Diagramatic illustration, drawn to same scale, of the relative size and alignment of the upper jaw of the three specimens of figure 6. The lines of dashes align the tip of the upper lip with the center of the base of the caudal rays.

and McGintys, June 1952, 80 fathoms. MCZ 39534 (1) 29.5 mm. S.L., 18 miles east of Delray, Florida, 22 May 1948, 300-325 fathoms. SAFI collection (1) 23.5 mm. S.L., COMBAT Sta. 457, 25°16′N., 80°07′ W., about 35 miles south of Miami, Florida, 26 July 1957, 65 fathoms. ANSP 74840 (1) 32 mm. S.L., south of Sombrero Light Key, Florida, by A. R. Thompson and McGintys on the TRITON, July 1952. ANSP 75409 (1) 26 mm. S.L., southeast of Sound Key Light, edge of Pourtales Plateau, Key West, Florida, 90 fathoms. USNM 116755 (1) 39 mm. S.L., Carnegie Inst. Act. No. 144662, Tortugas, Florida, by W. H. Longley. USNM 171784 (1) 45.5 mm. S.L., south of Tortugas, Florida, by W. H. Longley, 19 July 1932, 83-94 fathoms. SAFI collection (1) about 19 mm. S.L. (caudal peduncle missing), from stomach contents of *Thunnus atlanticus* (Lesson), caught surface trolling on THEODORE N. GILL Cruise 4, approximately 26°55′N., 78°55′W., southwest of Grand Bahama Island, 3 October 1953. CNHM 64461 (29) 38.5 to 118 mm. S.L., OREGON Sta. 1026, 25°08′N., 84°19′W., about 81 miles westnorthwest of Tortugas, Florida, 19 April 1954, 163 fathoms. GCRL collection (1) 31.5 mm. S.L., OREGON Sta. 32, 29°10′N., 85°55′W., about 43 miles southwest of Cape San Blas, Florida, 23 June 1950, 95 fathoms. CNHM 64382 (1) 100 mm. S.L., OREGON Sta. 1343, 22°59′N., 79°17′W., southeast of Cay Sal Bank and about 27 miles off the mainland of Cuba, 16 July 1955, 250 fathoms. USNM 159595 (6) about 36 to 65 mm. S.L., OREGON Sta. 1868, 16°36′N., 82°37′W., about 95 miles northeast of Laguna Caratasca, Honduras, 21 August 1957, 175 fathoms. USNM 159596 (2) 41.5 and 42 mm. S.L., OREGON Sta. 1902, 11°27′N., 83°11′W., about 35 miles east of southern coast of Nicaragua, 9 September 1957, 135 fathoms. SAFI (1) 29.5 mm. S.L., OREGON Sta. 2356, 17°33′N., 63°35′W., northwest of Saba Bank, Saba, Leeward Islands, 25 September 1958, 125-132 fathoms. CNHM 64461 (4) 70.5 to 84.5 mm. S.L., OREGON Sta. 1983, 09°53′N., 59°53′W., off British Guiana, 3 November 1957, 125 fathoms. CNHM 64462 (3) 57 to 71 mm. S.L., OREGON Sta. 1986, 09°39′N., 59°47′W., off British Guiana, 4 November 1957, 100 fathoms. CNHM 64463 (1) 60 mm. S.L., OREGON Sta. 1987, 09°36′N., 59°44′W., off British Guiana, 4 November 1957, 80 fathoms. USNM 159601 (75) 39.2 to 83 mm. S.L., OREGON Sta. 2013, 07°30′N., 54°16′W., about 95 miles north of the eastern coast of Surinam, 8 November 1957, 125 fathoms. SAFI collection (12, 7 cleared and stained) 53.5 to 71.5 mm. S.L., OREGON Sta. 2013 (data as above). BOC 3739 (2) 61.5 and 70 mm. S.L., OREGON Sta. 2013. CNHM 64448 (2) 52 and 73 mm. S.L., OREGON Sta. 2013. SU 51022 (2) 63 and 78 mm. S.L., OREGON Sta. 2013. UF 5243 (2) 57.5 and 77 mm. S.L., OREGON Sta. 2013. TU 18373 (2) 61 and 69 mm.

S.L., Oregon Sta. 2013. MCZ 39983 (2) 62.5 and 67.5 mm. S.L., Oregon Sta. 2013. CU 31615 (2) 63.5 and 66.5 mm. S.L., Oregon Sta. 2013. UMML 2554 (2) 67 and 74.5 mm. S.L., Oregon Sta. 2013. ANSP 82168 (2) 57 and 77.5 mm. S.L., Oregon Sta. 2013. MMF collection (2) 63.5 and 75 mm. S.L., Oregon Sta. 2013. BMNH 1958.6.20 (2) 66.5 and 75.5 mm. S.L., Oregon Sta. 2013. MNRJ 9.010 and 9.011 (2) 65 and 73 mm. S.L., Oregon Sta. 2013. CNHM 64464 (5) 61.5 to 69 mm. S.L., Oregon Sta. 2013. USNM 159598 (4) 37.5 to 66 mm. S.L., Oregon Sta. 2066, 02°40′N., 47°55′W., about 190 miles northeast of mouth of Amazon River, Brazil, 15 November 1957, 110 fathoms. SAFI collection (1, cleared and stained) 65.5 mm. S.L., Oregon Sta. 2066 (data as above). CNHM 64465 (6) 58.5 to 81 mm. S.L., Oregon Sta. 2066 (data as above). CNHM 64466 (1) 32 mm. S.L.,

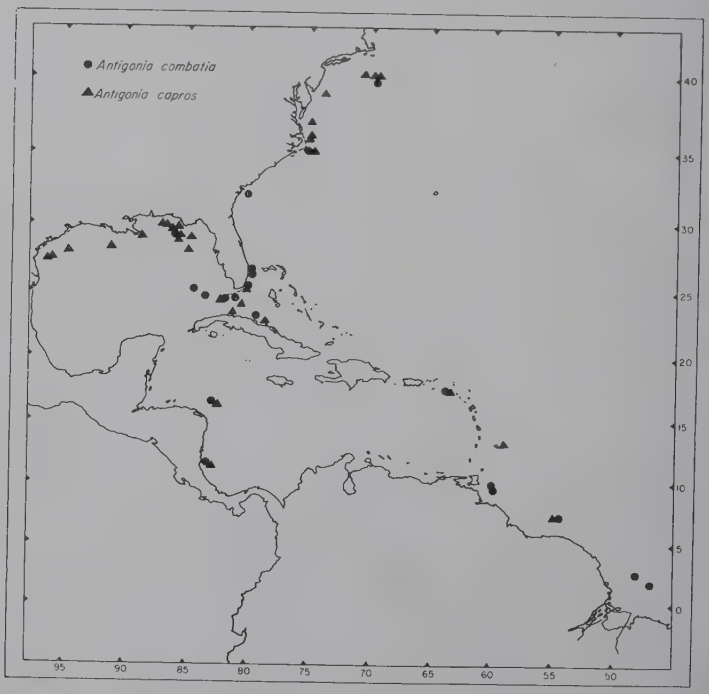

Figure 8. Distribution of *Antigonia combatia* and *A. capros* in the western Atlantic. Records of *A. capros* from Rio de Janeiro, Brazil (22°55′ S., 43°19′ W.), are not included.

Oregon Sta. 2083, 01°49′N., 46°48′W., about 200 miles northeast of mouth of Amazon River, Brazil, 17 November 1958, 225 fathoms.

Specimen examined: SAFI (1) 68.5 mm. S.L., Oregon Sta. 2291, 07°27′N., 54°27′W., about 80 miles northward of Paramaribo, Surinam, 9 September 1958, 120-135 fathoms.

Antigonia capros Lowe, 1843
(Figures 10 and 11)

Antigonia capros Lowe, 1843, p. 85 (Madeira).—Günther, 1887, p. 44 (in part; Madeira; Barbados).—Jordan, 1887, p. 577 (based on records of Lowe 1843 and Müller and Troschel 1849).—Goode and Bean, 1895, p. 229 (in part; based on records of Lowe 1843 from Madeira, Müller and Troschel 1849 from Barbados, and Günther 1887 from Barbados and Madeira; excluding fig. 235 which is *A. rubescens*).—Jordan and Evermann, 1896, p. 419 (in part; based on records of Lowe 1843 and Müller and Troschel 1849; excluding Pacific records).—Jordan and Evermann, 1898, p. 1665 (in part; based on records of Lowe 1843 from Madeira and Müller and Troschel 1849 from Barbados; excluding *A. mulleri* and *A. rubescens* from synonymy).—Miranda Ribeiro, 1903, p. 175 (Brasil).—? Osorio, 1909, p. 67 (Ilha de Santo Antao, Cape Verde Islands).—? Clark, 1913, p. 385 (Ascension Island).—Miranda Ribeiro, 1915 (Brasil).—Miranda Ribeiro, 1918, p. 76 (in part; synonymy; excluding *H. rubescens* and *A. mulleri*).—? Roule, 1919, p. 52 (southeast of Flores, Azores, 1360 meters; no description).—Jordan, Evermann, and Clark, 1930, p. 358 (based on records of Lowe 1843 and Müller and Troschel 1849).—? Firth, 1931, p. 162 (75 to 90 miles southeast of Cape Henry, Virginia, 28 to 50 fathoms; no description).—Fowler, 1936, p. 894 (in part; based on records of Lowe 1843, Clark 1913, and Roule 1919 from Madeira, Ascension, and Azores; excluding fig. 381 which is *A. rubescens*), ? p. 1306 (based on record of Osorio 1909 from Cape Verde Islands).—Cadenat, 1937, p. 491, fig. 36 (from seven stations off West Africa at Cape Verde Islands, Senegal, and French Guinea, between depths of 120 and 265 meters).—Longley and Hildebrand, 1941, p. 146 (in part; off Tortugas, Florida, 40 to 140 fathoms; probably also included specimens of *A. combatia*).— ? Hildebrand, 1941, p. 228 (based on record of Firth 1931).—Howell Rivero, 1941, p. 344 (Matanzas, Cuba).—Fowler, 1941a, p. 169 (based on record of Miranda Ribeiro 1903 from Rio de Janeiro, Brazil).—Raney and Ross, 1947, p. 63 (off Block Island, Rhode Island, 53 fathoms).—? Maul in Noronha and Sarmento, 1948, p. 78 and 149 (Madeira; no description).—Fraser-Brunner, 1950, p. 722 (Madeira; Barbados).—Bigelow and Schroeder, 1953, p. 438, fig. 225 (south of Nantucket Lightship, off Massachusetts, 55 to 80 fathoms).—Springer and Bullis, 1956, p. 89 (in part; specimens examined and records verified for Oregon Stations 156, 273, 277, 278, 326, 602, 732, 864, 895, and 945; excluding records from Oregon Stations 32, 1026, and 1343 which are *A. combatia*).—? Salzen, 1957, p. 77 (Gold Coast, West Africa; no description).—Briggs, 1958, p. 271 (from Rhode Island to Rio de Janeiro and the northern Gulf of Mexico; compiled).

Caprophonus aurora Müller and Troschel, 1849, p. 28, pl. V, fig. 1 (Barbados).

Antigonia browni Fowler, 1934, p. 356, fig. 8 (about 50 miles southeast of Five-fathom Bank Light Ship, New Jersey); 1935, p. 9 (reference to Fowler 1934);

1937, p. 302, (Cape Henry, New Jersey); 1952, p. 119 (New Jersey; listed).—Briggs, 1958, p. 271 (in part; New Jersey; compiled).

? *Antigonia otwayi* (*nomen nudum*) Fowler, 1941b, p. 59 (*lapsus calami* ?; "Deep Boar Fish"; off New Jersey).

Synonyms and References: References are included only for the Atlantic Ocean. Identifications by name only, with no description or illustration that can be identified, are questioned because they may have included or have been composed of the previously undistinguished *A. combatia*.

Diagnosis: [5] An *Antigonia* with dorsal spines 8 (rarely 7 or 9), dorsal softrays 31 to 37, anal softrays 29 to 34, pectoral I-13 (rarely I-12 or I-14), scale rows about 46 to 54, body depth 136.0 to 98.3, third (longest) dorsal spine length 44.5 to 23.3, first (longest) anal spine length 21.6 to 13.9, pelvic spine length 37.2 to 24.1, upper jaw length 10.2 to 7.3.

Description: Counts and measurements are given in tables 1, 2, and 3. Body compressed and elevated. Greatest vertical body depth 136.0 to 98.3, apparently increasing in proportion to S.L. with growth to about 50 or 60 mm. S.L. and decreasing in proportion to S.L. above this size (fig. 9; compare specimens in figs. 10 and 11). Snout to 1st dorsal spine 77.2 to 59.6, decreasing in proportion to S.L. with growth. Snout to pectoral origin 46.1 to 36.2, decreasing in proportion to S.L. with growth. Snout to pelvic origin 86.0 to 67.8, decreasing in proportion to S.L. with growth. Snout to 1st anal spine 92.7 to 76.4, decreasing in proportion to S.L. with growth. Caudal peduncle deeper than long, its depth at caudal base 16.9 to 12.8, tending to decrease in proportion to S.L. with growth. Lateral line as in *A. combatia*.

Head length 42.3 to 33.9, decreasing in proportion to S.L. with growth. Body outline becoming shallower with growth, but anteriodorsal profile remaining characteristic with slight concavities between snout and upper end of supraoccipital crest and between upper end of supraoccipital crest and dorsal fin origin. Snout length 8.8 to 11.7, increasing nearly in direct proportion to S.L. with growth. Cleft of mouth angular, and lower jaw slightly projecting. Upper jaw length 7.3 to 10.2, increasing nearly in direct proportion to S.L. with

[5] Only values for specimens from the Atlantic Ocean are given. The numbers after each character are the ranges in values for these specimens. Where the proportion decreases with growth, the larger extreme of the range is placed first. Body proportions are in percent of standard length. This procedure is followed in the Description.

growth. Eye diameter 20.2 to 13.4, decreasing in proportion to S.L. with growth. Denticulated ridges on head similar to *A. combatia.*

Teeth similar to *A. combatia.*

Gillrakers 5 to 6 + 13 to 16. Branchiostegals 6.

Dorsal spines 8 (rarely 7 or 9) (table 1). One specimen with 9 dorsal spines has the 5th spine split to about one-third of the distance from the tip forming two points and with the 9th spine appearing normal. X-ray of another specimen with 9 spines shows that the 9th spine abnormally has no interneural spine associated with it. Third spine the longest 44.5 to 23.3, decreasing in proportion to S.L. with growth. Spines in graduated length series and 1st and 2nd dorsal fins connected as in *A. combatia.*

Anal spines 3. First spine the longest 21.6 to 13.9, decreasing in proportion to S.L. with growth. Graduation of spines and connection to 1st anal softray as in *A. combatia.*

Dorsal softrays 31 to 37. Anal softrays 29 to 34 (table 2). A 128-mm. specimen has an abnormal anal fin consisting of only two spines and 26 softrays, with the first two softrays hardened and shortened like spines but possessing segment marks (the dorsal fin of this fish has 9 spines and 33 softrays). Approximate length of softrays, branching, and basal sheath as in *A. combatia.* Anal fin base length 69.8 to 52.5, decreasing in proportion to S.L. with growth.

Caudal fin subtruncate. Caudal principal rays 6 + 6 (in all specimens examined). Caudal secondary rays 4 + 3 (in two stained specimens). Branching of rays and scales on caudal as in *A. combatia.*

Pectoral fin bluntly pointed. Pectoral rays I-13 (rarely I-12 or I-14) (table 1). Pectoral length 43.5 to 31.1, decreasing in proportion to S.L. with growth. Relative growth of spine, branching and comparative length of rays, and insertion of pectoral as in *A. combatia.*

Pelvic fin pointed. Pelvic rays I-5 (in all specimens). Pelvic spine length 37.2 to 24.1, decreasing in proportion to S.L. with growth (fig. 5). Membranes connecting rays, comparative lengths of rays, and insertion as in *A. combatia.*

Scale rows about 46 to 54. Scalation of head, body, and fins, and structure of scales essentially similar to that of *A. combatia.*

Pigmentation essentially faded out on most preserved specimens; in these pigment is most prominent in dark interray membranes of the pelvic fins (pronounced on specimens up to about 70 mm. S.L., less so on largest specimens); slight dark pigment on interspinous membranes of dorsal fin in smaller specimens; a thin diagonal line extends perpendicular to and along the proximal ends of the interneural spines, another along proximal ends of interhemal spines, and

a third thin line along lateral midline of body (these of contrasting dark on specimens in alcohol, yellowish-orange on specimens in formalin). Three fresh specimens from the vicinity of Portsmouth, Virginia, were examined about 3 days after capture: the 116-mm. and 128-mm. specimens had dark red bodies and reddish fins; the 65.5-mm. specimen had a dark red bar extending through the eye, another from the spinous dorsal base to the pelvic insertions, and a broad bar-like mass of dark red pigment beginning at the middle of the soft-ray bases and diminishing in intensity onto the peduncle, with the snout and the interbar spaces colored silvery pink, the fins reddish, and the distal margin of the pelvics black. Two specimens from south of Martha's Vineyard, 44.5 and 61.5 mm. S.L., examined 15 days after capture and preservation in formalin, were similar in color to the 65.5-mm. specimen described above, but faded. Fowler (1934: 356) described similar bars from the holotype of *A. browni* as rose pink when fresh. Raney and Ross (1947: 63) described the body color of a 109-mm. specimen from Block Island Sound (CU 10454) as still pale red after 9 days in formalin.

Distribution: *Antigonia capros* is recorded from off the eastern coasts of North, Central, and South America, from the northern Bahamas, northern Cuba, the Leeward Islands, and the Barbados (fig. 8). The species in this area ranges from off southern Massachusetts to Rio de Janeiro, Brazil. Miranda Ribeiro (1903: 175 and 1915) reported *A. capros* from Brazilian waters. Antenor Leitao de Carvalho of the Universidade do Brasil informed me (personal communication) that the 75-mm. S.L. specimen reported by Miranda Ribeiro (1903 and 1915) and seven specimens of 85 and 150 mm. S.L. collected later from the same locality, around the Ihla Rasa in front of Guanabara Bay a few miles east of Rio de Janeiro, are in the Museu Nacional. Paul Kähsbauer, of Wien Naturhistorisches Museum, wrote (personal communication) that the 135-mm. T.L. specimen, reported by Miranda Ribeiro (1915), 112 mm. S.L., collected at Ilha Cava, Rio de Janeiro, Brazil, is in the Naturhistorisches Museum. The species occurs at Madeira and apparently off the western and eastern coasts of Africa, off India and Australia, in Indonesia and the Philippines, off Japan, and in the Hawaiian Islands. It has not been reported from the western coast of the American continents.

William C. Schroeder, Woods Hole Oceanographic Institution, generously furnished the following previously unreported records from off the northeastern United States: 40°00′ N., 69°50′ W., March 1954, 75 fathoms, (14 specimens) 61 to 116 mm. S.L., MCZ 38645.

39°59′ N., 69°35′ W., July 1952, 82-85 fathoms, (1) 34 mm. S.L., MCZ 37680. 38°26′N., 73°34′W., March 1954, 70 fathoms, (1) 88 mm. S.L., MCZ 38630. 37°51′ N., 74°09′ W., June 1953, 70-72 fathoms, (1) 42 mm. S.L., MCZ 38178.

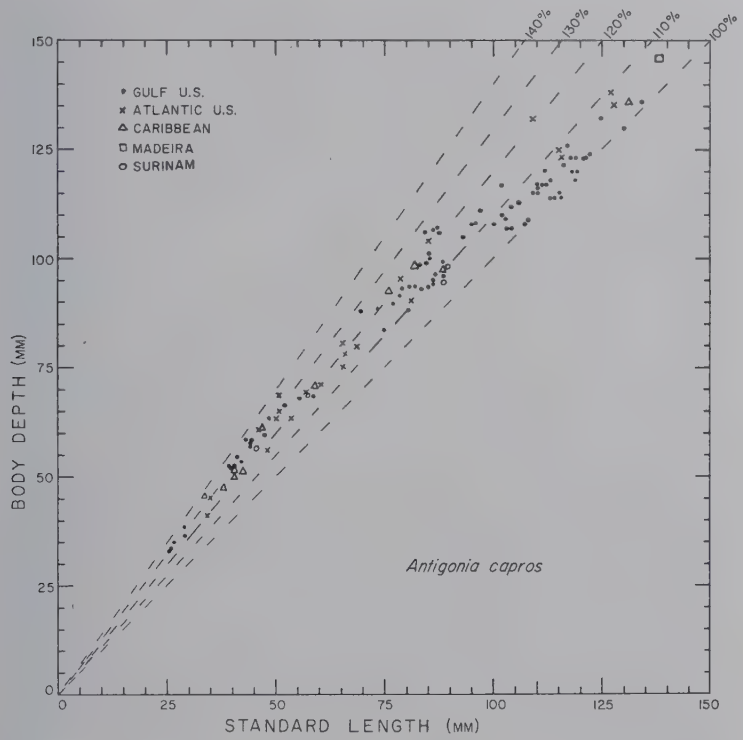

Figure 9. Relation of body depth to standard length for *Antigonia capros* from four different areas. Reference lines of dashes represent proportional (percentage) values; at "120%" body depth is 120% or twelve-tenths of standard length.

Development and Geographic Variation: Within the size range of specimens examined, all the body parts measured except body depth increase with growth at a slower rate than the standard length (table 3). Body depth (fig. 9) increases faster than standard length to about 50 or 60 mm. S.L., and above this size increases more slowly than standard length (a 6.2-mm. S.L. larval specimen, identified as *A. capros*, has a body depth of 83.9% S.L.). The snout and upper jaw

apparently grow at a constant rate with respect to standard length, but the other body parts measured do not—these apparently having a curvilinear or inflected rectilinear growth pattern in relation to standard length.

Figure 10. Left and lower right: *Antigonia capros,* 52 and 25.5 mm. S.L. Upper right: *Antigonia combatia,* 45.5 mm. S.L. Taken together south of Tortugas, Florida, 19 July 1932, USNM 116755 and 171784.

Geographic variation in development, as was postulated for *A. combatia,* is suggested by comparisons of larger specimens (109 to 128 mm. S.L.) from off the northeastern United States with specimens of similar size from the Gulf of Mexico and of the two largest Surinam specimens (88.5 and 89 mm. S.L.) with Gulf of Mexico specimens. The larger northeastern U. S. specimens average greater measurements and the Surinam specimens average smaller measurements of body depth (fig. 9), 3rd dorsal spine length, 1st anal spine length, pelvic spine length, and snout to pelvic and snout to 1st anal spine distances than do similar sized Gulf of Mexico specimens. Similar comparisons of smaller specimens do not appear to manifest this phenomenon, so that if geographic variation does occur, it may not be apparent at smaller body sizes (generally at less than 80 or 100

mm. S.L.). The few specimens from the Caribbean do not appear to differ greatly from specimens from the other areas.

Figure 11. *Antigonia capros,* 130 mm. S.L., OREGON Sta. 273, 29°09′ N., 88°59′ W., Gulf of Mexico, USNM 158636. Depth equals standard length.

The single specimen examined from the Eastern Atlantic, 138 mm. S.L., BMNH 1864.8.24.3, from Madeira, collected by Johnson, reported as *A. capros* by Günther (1887: 44), is the largest Atlantic specimen I have examined. Its ratios of body depth, snout to pelvic and snout to 1st anal spine distances, and 3rd dorsal spine length to standard length are comparable to those of slightly smaller specimens from the Western Atlantic off the northeastern United States, but its ratio of eye diameter to standard length is slightly greater.

Five specimens from the Indo-Pacific I have examined are referable, on the basis of the number of dorsal and anal softrays, dorsal spines, and general depth of body, to *Antigonia capros*. One specimen, 155 mm. S.L., TU 10776, from the Honolulu market, Hawaii, is the largest *Antigonia* I have examined, but it appears to be identical in all respects to Atlantic *A. capros*; its body depth is 102.6% S.L. The second specimen, 128 mm. S.L., USNM 51036, from Hilo, Hawaiian Islands, identified as the synonymous *A. steindachneri* by Jordan and Evermann (1905: 361, No. 03702), has a body depth of 113.3% S.L., greater than that of the 5 specimens examined of Atlantic *A. capros* of comparable length (127-138 mm. S.L.), but this may be attributable to geographic or individual variation. The third specimen, 89 mm. S.L., BMNH 1921.3.1.30, identified as *A. capros* by Fraser-Brunner (1950: 722), compared to Atlantic specimens of *A. capros* has a slightly different body outline, a straighter and thinner 3rd dorsal spine and 1st anal spine, the pelvic fins inserted more posteriorly, a shorter upper jaw (6.7% S.L.), and a slightly shorter pelvic spine (23.8% S.L.). The fourt specimen, 52 mm. S.L., BMNH 1871. 7.20.145, from Manado, Celebes, identified as *A. browni* by Fraser-Brunner (1950: 722), compared to Atlantic specimens of *A. capros* has the profile formed by the bases of the dorsal and anal softrays almost straight rather than convex, 3rd dorsal and 1st anal spines straighter and thinner, and a slightly shorter pelvic spine (25.0% S.L.). The fifth specimen, 42.5 mm. S.L., BMNH 1879.5.14.340, from the Kai Islands, Banda Sea, identified as *A. capros* by Fraser-Brunner (1950: 722), compared to Atlantic specimens of *A. capros* has a body depth (109.4% S.L.), less than that of all *A. capros* specimens examined of about this size, and it has a slightly shorter pelvic spine (23.5% S.L.). This specimen might be referred to *A. eos* except that it has only 8 dorsal spines, and even this reservation is uncertain. Broken dorsal and anal spines of the three smallest specimens limit taxonomic assessment. The Hawaiian specimens agree with Atlantic specimens of *A. capros*—the others differ in certain respects.

Relationships: *Antigonia capros* Lowe, 1843, from Madeira, is accepted *prima facie* as the scientific name applicable to the specimens so identified from the Atlantic Ocean. Lowe (1843: 85) had no illustration and gave no mention of the deposition of his type, but his listing of "D. 8 + 34; A. 3 + 33" excludes *A. combatia* from consideration. He referred to his specimen as a "little fish," but in view of the poetic phrases embellishing his descriptions and of the interposition of the description of *A. capros* among the descriptions of speci-

mens of other species "five-eighths of an inch less than three feet" and "thirteen inches and a quarter long" the actual length of his specimen of *A. capros* cannot be determined.

Caprophonus aurora Müller and Troschel, 1849, from Barbados, Lesser Antilles, is identical to *A. capros*. Müller and Troschel (1849: 28) gave counts of D. VIII-34, A. III-32. Their figure (pl. V, fig. 1) is apparently a natural size reproduction (1:1) of their type specimen, which they described as being about 6 inches in total length. The standard length and the depth of the figure (and presumably of the type specimen) are both about 120 mm.

Antigonia browni Fowler, 1934, was described from a specimen taken about 50 miles southeast of Five-fathom Bank Light Ship, off New Jersey. Examination of the type specimen (51 mm. S.L., 65.5 mm. T.L., ANSP 60173) and comparison of its characters with the relatively large series of *A. capros* justifies my synonymization of *A. browni* with *A. capros*. *A. browni* is actually a growth stage of *A. capros*. The specimens from the western Atlantic that I have identified as *A. capros* collectively demonstrate the growth changes connecting these two forms. Hildebrand in Longley and Hildebrand (1941: 147) and Raney and Ross (1947: 63) expressed doubt on the distinctness of the two forms. Fowler's original suggestions of the distinctness of *A. browni* were based mainly on growth differences and what is probably attributable to geographic variation between his small specimen (51 mm. S.L.) from off New Jersey and the larger *Caprophonus aurora* of Müller and Troschel from Barbados (about 120 mm. S.L.). Fowler (1934: 358) referred to differences in color of *A. browni* and *C. aurora*—Hildebrand (1941: 147) suggested that these differences were due to preservation; I concur with Hildebrand and add that the prominent pigmentation on the pelvics and of vertical body bars or bands on small specimens apparently tends to moderate and disappear with growth. Fowler contrasted the convex caudal fin of *A. browni* with the emarginate caudal of Müller and Troschel's illustration of *C. aurora* and Lowe's description of a truncate tail for *A. capros* —I have examined specimens with caudal fins that are rounded on their dorsal and ventral edges to an almost convex shape, others that appear nearly truncate, and some that are slightly broken or worn to appear emarginate, and therefore describe the caudal fin shape as subtruncate. The differences in contour ascribed by Fowler to occur between *A. browni* and *C. aurora* are illustrated as size differences in comparison of figures 9, 10, and 11. Fowler inferred that *A. browni*

had a longer pectoral fin than *A. aurora*—the decrease in the proportional length of the pectoral (in % S.L.) is evident from table 3.

Fraser-Brunner (1950: 722) identified two small specimens in the British Museum (Natural History) from Manado (Celebes) as *A. browni*, and reported that these were the specimens identified as *Hypsinotus rubescens* by Meyer (1885: 18). Fraser-Brunner (1950) distinguished *A. browni* from *A. capros* as: *A. browni* with 3rd dorsal spine longer than head, shorter in *A. capros*; and *A. browni* with depth of body much greater than standard length, depth equal to standard length or but little greater in *A. capros*. In initial consideration of Fraser-Brunner's treatment, three of the five Pacific specimens that I have examined that are meristically and morphometrically similar to *A. capros* have certain differences, discussed above, that suggest that some of the Indo-Pacific forms referred to *A. capros* may be specifically different from the Atlantic *A. capros*. I have examined a 52-mm. S.L. specimen (BMNH 1871.11.28.63) identified as *A. browni* by Fraser-Brunner, and information of the other specimen so identified has been kindly furnished by G. Palmer of the British Museum. Palmer (personal communication) described the second specimen as about 58 mm. S.L., but with part of the head missing and therefore difficult to measure. The end of the 3rd dorsal spine is missing from the 52-mm. specimen. Despite this, table 3 shows that while the 3rd dorsal spine and the head length decrease in proportion to the standard length with growth, the 3rd dorsal spine decreases faster than the head and, consequently, the 3rd dorsal spine will be shorter in proportion to the head in large specimens than it is in small specimens. I consider the differences in depth and 3rd dorsal spine length suggested by Fraser-Brunner to result from growth changes.

Antigonia steindachneri, described by Jordan and Fowler (1902: 522) from specimens from the Hawaiian Islands, has since been relegated by most authors to the synonymy of *A. capros*. In their proposal to split the Atlantic and Pacific forms of *A. capros* taxonomically, Jordan and Fowler (*op. cit.*) were very brief in their distinction, saying, "The two species [*A. capros* and *A. steindachneri*] are closely related, but apparently distinct." A 128-mm. specimen from the Hawaiian Islands, identified as *A. steindachneri* by Jordon and Evermann (1905: 361) and discussed above, appears to be identical to Atlantic specimens of *A. capros*.

Antigonia eos, described by Gilbert (1905: 621, pl. 80, fig. 1) from specimens taken at six Albatross stations in the Hawaiian Islands, is currently known only from Gilbert's holotype and paratypes. I

have examined the holotype (65.5 mm. S.L., USNM 51593) and seven paratypes (24.5 to 59 mm. S.L., USNM 51686) and consider them specifically distinct from *A. capros*, but I have not been able to separate the two species completely by morphological characters. *A. eos* differs from *A. capros* in normally having one more dorsal spine (9 spines in all specimens reported by Gilbert and confirmed in the USNM types; 9 spines present in only 3 of 103 specimens of *A. capros* examined). *A. eos* averages one less pectoral softray than *A. capros* (one spine and 12 softrays counted on both sides of the USNM types, Gilbert did not distinguish the spine and gave a count of "P. 13."; 100 specimens of *A. capros* had a spine and 13 or 14 softrays, only three specimens had 12 softrays and these three had 13 softrays on the alternate side). *A. eos* apparently averages a lesser body depth than *A. capros* at sizes larger than about 50 mm. S.L., but the species may be indistinguishable by this character at smaller sizes (four types of *A. eos* of 57 to 65.5 mm. have body depths of 100.8 to 98.5% S.L.; interpretation on figure 9 of the coordinates of *A. capros* indicates body depths of 115 to 133% S.L. for this species within the above size range). Meager evidence suggests that *A. eos* has a longer 3rd dorsal spine than *A. capros*, but distinguishing the species on this basis is quantitatively impossible at present. Although Gilbert gave the length of the 3rd dorsal spine as 45 percent of the standard length, he mentioned that the tip was injured, his type illustration (pl. 80, fig. 1) represents the posterior third of this spine by a contrasting dotted line, and the length of the broken spine remaining on the holotype is only about 13% S.L. The 3rd dorsal spine of all the USNM paratypes is broken, and at least the terminal halves of the spines must be missing. Gilbert described differences in the shape and structure of the scales of *A. eos* and *A. steindachneri* (= *A. capros*), but these described differences might be attributable to intraspecific variation or variation with growth. The dorsal and anal softrays of the USNM types are: D. 33, A. 31 (1 specimen); D. 32, A. 30 (2); D. 31, A. 30 (4); and D. 31, A. 29 (1).

Specimens examined: MCZ 38181 (1) 51 mm. S.L., Capt. Bill II Sta. 221, 40°04′N., 70°34′W., about 77 miles south of Martha's Vineyard, Massachusetts, 29 July 1953, 70-75 fathoms. NAFI collection (2 specimens) 44.5 and 61.5 mm. S.L., approximately 40°03′N., 70°38′W., about 80 miles south of Martha's Vineyard, Massachusetts, by the Dorthy and Betty II, 11 March 1958, 75 fathoms. MCZ 37194 (4) 34.5 to 66 mm. S.L., Eugene H, 40°00′N., 69°50′W., about 75 miles south of Nantucket Island, Massachusetts, 25 March 1951, 76

fathoms. CU 10454 (1) 109 mm. S.L., 58 miles south-half-east of Block Island, Rhode Island, by Wm. F. Royce on New Dawn, 12 March 1946, 53 fathoms. ANSP 60173 (1) 51 mm. S.L., 50 miles southeast Five Fathom Bank, New Jersey, March 1934. ANSP 72098 (1) 127 mm. S.L., 40 miles southeast of Ventnor, New Jersey, by C. B. Atkinson, 1945. USNM 127410 (2) 78.5 and 85 mm. S.L., Cape Henry, Virginia, Seriano II, 6 April 1931, 50-60 fathoms. USNM 120992 (2) 46 and 57 mm. S.L., 80 miles southeast of Cape Henry, Virginia, by H. H. Iltis, Sea Roamer, 11 February 1944, 100 to 150 fathoms. SAFI collection (3) 65.5 to 128 mm. S.L., landed at Portsmouth, Virginia, about 15 April 1958 (presumably taken from the Portsmouth area at about this date, but definite data lacking; trucked into Lewis Crab Co., Brunswick, Georgia). SAFI collection (5, 2 cleared and stained) 48 to 115 mm. S.L., Combat Sta. 370, 35°05′N., 75°09′W., about 20 miles ESE of Cape Hatteras Bight, North Carolina, 6 June 1957, 100 fathoms. CNHM 64377 (1) 50 mm. S.L., Combat Sta. 384, 34°54′N., 75°25′W., about 20 miles ESE of Cape Hatteras Bight, North Carolina, 17 June 1957, 75 fathoms. BBL (1) 35 mm. S.L., southeast of North Edisto River sea buoy off South Carolina by T-19 (about 50 miles southeast of Edisto Island), 25 February 1958, 37 fathoms. SAFI collection (1) 26 mm. S.L., Combat Sta. 457, 25°16′N., 80°07′W., about 16 miles east of Key Largo, Florida, 26 July 1957, 65 fathoms. MCZ 39435, Harvard-Havana Expedition Atlantis Sta. 3393, 22°36′N., 78°19′W., about 6 miles northeast of Cayo Coco, Cuba, 27 April 1939, 210 fathoms. MCZ 37156, Harvard-Havana Expedition Atlantis Sta. 3480, 23°10′N., 81°28′W., off Matansas, Cuba, 11 May 1939, 200 fathoms. GCRL (1) 73.5 mm. S.L., Oregon Sta. 1349, 24°03′N., 80°30′W., northeast of Cay Sal Bank, Florida Straits, 18 July 1955, 150 fathoms. USNM 116754 (2) 25.5 and 52 mm. S.L., south of Tortugas, Florida, by W. H. Longley, 19 July 1932, 83-94 fathoms. USNM 92055 (1) 55.5 mm. S.L., south of Tortugas, Florida, by Longley, 18 August 1931. TU 12967 (3) 40 to 79 mm. S.L., Oregon Sta. 895, 28°47′N., 85°19′W., about 53 miles south of Cape San Blas, Florida, 7 March 1954, 64 fathoms. USNM 163521 (5) 43 to 87 mm. S.L., Oregon Sta. 920, 28°00′N., 84°54′W., west of Tampa, Florida, 11 March 1954, 80 fathoms. UF collection (2) 84 and 87.5 mm. S.L., Oregon Sta. 920 (data as above). USNM 159599 (3) 83.5 to 88.5 mm. S.L., Silver Bay Sta. 154, 28°58′N., 84°44′W., about 44 miles south of Apalachicola Bay, Florida, 22 August 1957, 76-81 fathoms. CNHM 45566 (1) 26.5 mm. S.L., Oregon Sta. 732, 28°50.8′N., 85°28′W., about 50 miles south of Cape San Blas, Florida, 17 December 1952, 57

fathoms. CNHM 46569 (6) 39 to 100 mm. S.L., Oregon Sta. 277, 28°48′N., 85°40′W., about 56 miles south of Cape San Blas, Florida, 23 February 1951, 104 fathoms. USNM 158519 (4) 104 to 134 mm. S.L., Oregon Sta. 278, 29°49′N., 85°45′W., off Cape San Blas, Florida, 24 February 1951, 112 fathoms. USNM 155670 (1) 44 mm. S.L., Pelican Sta. 154-2, 29°08.5′N., 85°47′W., about 39 miles southwest of Cape San Blas, Florida, 10 March 1939, 70 fathoms. UF 3551 (2) 103 and 116 mm. S.L., Oregon Sta. 864, 29°19′N., 86°04′W., about 43 miles southwest of Cape San Blas, Florida, 31 October 1953, 82 fathoms. TU 12979 (3) 80.5 to 119 mm. S.L., Oregon Sta. 864 (data as above). GCRL collection (1) 58.5 mm. S.L., Oregon Sta. 603, 29°33.5′N., 86°13.2′W., about 40 miles west of Cape San Blas, Florida, 12 July 1952, 60 fathoms. TU 6071 (10) 77 to 125 mm. S.L., Oregon Sta. 602, 29°31.5′N., 86°21.4′W., about 54 miles south of Destin, Florida, 12 July 1952, 80 fathoms. USNM 155659 (1) 29 mm. S.L., Pelican Sta. 143-4, 29°44.5′N., 86°34.5′W., south of Panama City, Florida, 5 March 1939, 65 fathoms. UF collection (2) 47.5 and 69.5 mm. S.L., Oregon Sta. 945, 29°48′N., 86°37′W., about 36 miles south of Ft. Walton, Florida, 21 March 1954, 67 fathoms. TU 12809 (1) 118 mm. S.L., Oregon Sta. 326, 29°57′N., 86°57.5′W., about 31 miles south of Pensacola, Florida, 30 April 1951, 82 fathoms. TU 2032 (1) 79 mm. S.L., Oregon Sta. 326 (data as above). USNM 158636 (17) 85 to 130 mm. S.L., Oregon Sta. 273, 29°09′N., 88°59′W., about 4 miles off Pass a Loutre, Louisiana, 18 February 1951, 110 fathoms. CNHM 46571 (6) 86 to 121 mm. S.L., Oregon Sta. 273 (data as above). USNM 159594 (1) 86 mm. S.L., Silver Bay Sta. 179, 28°06′N., 91°09′ W., about 60 miles south of Terrebonne Bay, Louisiana, 21 September 1957, 75-100 fathoms. GCRL collection (2) 107 and 108 mm. S.L., Oregon Sta. 1514, 27°50′N., 94°45′W., about 70 miles off Freeport, Texas, 9 May 1956, 130 fathoms. CNHM 46570 (1) 39.5 mm. S.L., Oregon Sta. 156, 27°22′N., 96°08′W., about 56 miles southeast of Aransas Pass, Texas, 27 November 1950, 103 fathoms. CNHM 45215 (2) 41 and 44.5 mm. S.L., 27°20′N., 96°20′W., about 53 miles southeast of Aransas Pass, Texas, by J. L. Baughman, July 1952, 100 fathoms. SAFI (1) 33.8 mm. S.L., Oregon Sta. 2356, 17°33′N., 63°35′W., northwest of Saba Bank, Saba, Leeward Islands, 25 September 1958, 125-132 fathoms. CNHM 64378 (4) 38 to 46.5 mm. S.L., Oregon Sta. 1867, 16°38′N., 82°43′W., about 95 miles northeast of Laguna Caratasca, Honduras, 21 August 1957, 140 fathoms. CNHM 64380 (1) 88.5 mm. S.L., Oregon Sta. 1869, 16°38′N., 82°34′W., about 95 miles northeast of Laguna Caratasca, Honduras, 21 August 1957, 205-210 fathoms.

CNHM 46379 (1) 59 mm. S.L., Oregon Sta. 1868, 16°36′N., 82°37′W., about 70 miles north of Laguna Caratasca, Honduras, 21 August 1957, 175 fathoms. USNM 159600 (4) 76 to 131 mm. S.L., Oregon Sta. 1868 (data as above). CNHM 64381 (1) 40.5 mm. S.L., Oregon Sta. 1902, 11°27′N., 83°11′W., about 28 miles east of Monkey Point, Nicaragua, 9 September 1957, 135 fathoms. SAFI (2) 88.5 and 89 mm. S.L., Oregon Sta. 2291, 07°27′N., 54°27′W., about 80 miles northward of Paramaribo, Surinam, 9 September 1958, 120-135 fathoms. SAFI (2) 45.5 and 57.5 mm. S.L., Oregon Sta. 2289, 07°25′N., 54°35′W., about 80 miles northward of Paramaribo, Surinam, 8 September 1958, 75-80 fathoms.

Remarks

The boarfishes apparently live in areas of continental and insular shelves and slopes. Most of the specimens examined were taken in bottom trawls where water depths ranged from about 37 to 325 fathoms, and published depth records are generally within this range. This does not justify, however, the assumption that they live at the depths at which the trawl hauls were made. Their laterally compressed bodies do not suggest a sea floor existence, and their stomachs contain mainly invertebrate plankton types that occur in epipelagic waters.

Antigonia combatia and *A. capros* exist sympatrically in the western North Atlantic. They were taken together in six of the collections examined. Their combined range has been demonstrated to extend from off southern Brazil to off the northern Atlantic coast of the United States. While *A. combatia* has been taken only from this area, *A. capros* also occurs in the eastern Atlantic. *A. capros* has been reported from the western Pacific and Indian Oceans, but comparison of Atlantic specimens with an adequate size range series of Indo-Pacific forms may prove that two or more similar species exist.

Larval specimens identified as *Antigonia* species (they will be described elsewhere) were taken on several cruises of the M/V Theodore N. Gill for the South Atlantic Fishery Investigations in near-surface waters of the Gulf Stream off the Atlantic coast of the southeastern United States. This indicates that the boarfishes have an offshore pelagic larval stage and therefore are subject to geographic dispersion by current systems. The title of a publication (Uchida, 1936) I have not seen seems to substantiate this hypothesis.

In describing *Antigonia capros*, Lowe (1843: 85) proposed the family name *Caproidae*. Müller and Troschel (1849: 63) placed their synonymous *Caprophonus aurora* in the family Scomberoidei. Günther

(1860: 63), apparently prior to his recognition of Lowe's publication, placed *Hypsinotus* (= *Antigonia*) in the family Squamipinnes. Bleeker (1876: 310) apparently did not consider the relationship of *Capros* and, having an incorrect date of Temminck and Schlegel's description of *Hypsinotus* (1844), used the family name Hypsinotoidei. McCulloch (1929) also did not record the relationship of *Capros* and, incorrectly (under present nomenclatorial rules) considering *Antigonia* and *Hypsinotus* to be homonyms of prior-named genera, initiated the family name of Caprophonidae. Jordan and Fowler (1902: 521) stated, "We use the name *Antigoniidae* in preference to *Capridae*, as *Capridae*, derived from *Capra*, is applied to the family of Goats. *Caproidae* used by Gill seems hardly admissible." Recent authors have variously used Caproidae or Antigoniidae. I follow Lowe (*loc. cit.*), Berg (1947: 468), and others in recording *Antigonia* Lowe and *Capros* Lacepede in the family Caproidae. The phylogenetic relationships of the family are so uncertain, despite the early work of Starks (1902) and Regan (1910), that among other conflicting opinions Tortonese (1943-48: 13) gave evidence for placing Caproidae in the Zeiformes, while Matsubara (1955: 928) recorded the family (as Antigoniidae) in Percida: Chaetodontina.

Capros aper Lacepede differs generically from species of *Antigonia* in the way the nasal bones are fused (joined across the front of the snout with the posterior extensions of the premaxillaries extending posteriodorsally under the nasals in *Capros*, a recess between the nasals containing the posterior extensions of the premaxillaries exposed along the dorsal profile of the snout in *Antigonia*), in the external sculpture of the head above the eye (no distinct pattern of ridges in *Capros*, a distinct pattern of 12 or more curved and serrated ridges in *Antigonia*), in the structure of the scales (with numerous conical spines on exposed portion in *Capros*, with elevated and frequently denticulated ridges and frequently bearing flattened spines on the exposed portion in *Antigonia*), and in several proportions and meristics. I have not been able to locate the deep-bodied, protractile-mouthed fish from the stomach of a chiasmodont taken off Puerto Rico that Erdman (1956: 339) suggested might be a young *Capros aper*. Dannevig (1917: 8) listed as *Capros aper* a specimen of 6 mm. total length from 49°24′ N., 58°55′ W., in the Laborador Sea, but this record was not described or illustrated and is not convincing. The substantiated range of *Capros aper* is the Mediterranean Sea and the eastern North Atlantic Ocean.

Literature Cited

Anderson, William W., and Jack W. Gehringer

1957. Physical oceanographic, biological, and chemical data, south Atlantic coast of the United States, *Theodore N. Gill* Cruise 4. U. S. Fish & Wildlife Service, Spec. Sci. Rept.—Fish. no. 234, p. 1-192, figs. 1-19.

Berg, L. S.

1947. Classification of fishes both recent and fossil. J. W. Edwards, Ann Arbor, Mich., English and Russian (from Trav. Inst. Zool. Acad. Sci. URSS, 1940, vol. 5, no. 2), p. 87-517, figs. 1-190.

Berry, Frederick H., and Warren F. Rathjen

1959. A new species of the boarfish genus *Antigonia* from the western Atlantic. Quart. Jour. Florida Acad. Sci. (1958), 21(3): 255-258.

Bigelow, Henry B., and William C. Schroeder

1953. Fishes of the Gulf of Maine. Fish. Bull. Fish & Wildlife Service, 53 (74): i-viii, 1-577, figs. 1-288.

Bleeker, Petro

1876. Systema Percarum revisum. Pars II. Archives Neerlandaises des Sciences Exactes et Naturelles, 11: 289-340.

1879. Enumeration des especes de poissons actuellement connues du Japon et description de trois especes inedites. Versl. Meded. Akad. Afd. Nat., 18: 1-33, 3 pls.

Boseman, M.

1947. Revision of the fishes collected by Burger and von Siebold in Japan. Zoologische Mededeelingen, 28: 1-242, pls. I-IV.

Briggs, John C.

1958. A list of Florida fishes and their distribution. Bull. Florida State Mus., Biol. Sci., 2(8): 223-318, figs. 1-3.

Cadenat, J.

1937. Recherches systematiques sur les Poissons littoraux de la Cote Occidentale d'Afrique, recoltes par le navire *President Theodore-Tissier,* au cours de sa 5e croisiere (1936). Revue des Travaux de l'Office Scientifique et Technique des Peches Maritimes, 10(4): 421-562, figs. 1-61.

Clark, R. S.

1913. Scottish National Antartic Expedition: "Scotia" collection of Atlantic fishes. (In Rept. Sci. Res. Voy. "Scotia," IV, part 16, p. 375-402, 5 figs.) Proc. Roy. Phys. Soc. Edinburg, 1915. (not seen)

Dannevig, Alf.

1917. Biology of Atlantic waters of Canada. Canadian fish-eggs and larvae. Canadian Fish. Exped., 1914-1915, Invest. Gulf St. Lawrence and Atl. waters Canada, p. 1-74, figs. 1-26, pls. I-III.

Erdman, Donald S.

1956. Recent fish records from Puerto Rico. Bull. Marine Sci. Gulf & Caribbean, 6(4): 315-340.

Firth, F. E.

1931. Rare fishes from off North Carolina. Copeia, 1931(4): 162.

Fowler, Henry W.

1934. The buckler dory and descriptions of three new fishes from off New Jersey and Florida. Proc. Acad. Nat. Sci. Philadelphia, 86: 353-361, figs. 1-9.

1935. Some deep water fishes from off New Jersey in 1934. Fish Culturist, 15(1): 7-9, 4 figs.

1936. The marine fishes of West Africa. Bull. Amer. Mus. Nat. Hist., 70 (pt. 2): 607-1493, figs. 276-559.

1937. Notes on fishes from the Gulf Stream and the New Jersey coast. Proc. Acad. Nat. Sci. Philadelphia, 89: 297-308, figs. 1-3.

1941a. A list of the fishes known from the coast of Brazil. Arquivos de Zoologia do Estado de São Paulo, 3(art. 6): 115-184.

1941b. New Jersey fish notes—1940. Fish Culturist, 20(8): 58-59.

1952a. Fishes from deep water off southern Florida. Notulae Naturae, no. 246, p. 1-16, figs. 1-10.

1952b. A list of the fishes of New Jersey, with off-shore species. Proc. Acad. Nat. Sci. Philadelphia, 104: 89-151, fig. 1.

Franz, Victor

1910. Die japanischen Knochenfische der Sammlungen Haberer und Dolfein. Abhandlungen der math. phys. Klasse der K. Bayer Akademie der Wissenschaften, München, 4(1): 1-132, pls. I-XI.

Fraser-Brunner, A.

1950. Note on the fishes of the genus *Antigonia* (Caproidae). Ann. Mag. Nat. Hist., Ser. 12, 3(32): 721-724.

Gilbert, Charles Henry

1905. The deep-sea fishes of the Hawaiian Islands. Bull. U. S. Fish Comm. (1903), 23(pt. II): 577-713, figs. 230-276, pls. 66-101.

Goode, George Brown, and Tarleton H. Bean

1895. Oceanic ichthyology. Bull. U. S. Natl. Mus., no. 2, vol. 1, xxv + 553 p., 24 text-figs.; vol. 2, xxiii + 26 p., pls. I-CXXIII

Günther, Albert

1860. Catalogue of the acanthopterygian fishes in the collection of the British Museum. Vol. 2, London, Taylor & Francis, xxi + 548 p.

1887. Report on the deep-sea fishes collected by H. M. S. Challenger during the years 1873-76. Rept. Sci. Results Voyage H. M. S. Challenger 1873-76, London, lxv + 335 p., pls. I-LXXIII.

Herre, A. W., and E. S. Herald

1950. Noteworthy additions to the Philippine fish fauna with descriptions of a new genus and species. Philippine Jour. Sci., 79: 309-340, 12 figs.

Hildebrand, Samuel F.

1941. An annotated list of salt and brackish water fishes, with a new name for a menhaden, found in North Carolina since the publication of "The fishes of North Carolina" by Hugh M. Smith in 1907. Copeia, 1941(4): 220-232.

Howell Rivero, L.

1941. *Antigonia capros* Lowe, nueva adicion a la fauna Cubana. Memorias de la Sociedad Cubana de Historia Natural "Felipe Poey," 15: 343-344.

Jordan, David Starr

1887. A preliminary list of the fishes of the West Indies. Proc. U. S. Natl. Mus., 1887(1886), 9(595): 554-608.

Jordan, David Starr, and Barton Warren Evermann

1896. A check-list of the fishes and fish-like vertebrates of North and Middle America. Rept. U. S. Comm. Fish & Fish. (1895), pt. 21, Appendix 5, p. 207-584.

1898. The fishes of North and Middle America. Bull. U. S. Natl. Mus., no. 47, pt. II, p. i-xxx, 1241-2183.

1905. The aquatic resources of the Hawaiian Islands. Part I.—The shore fishes. Bull. U. S. Fish Comm. (1903), 23(pt. I): i-xxviii, 1-574, figs. 1-229, pls. I-LXXIII.

Jordan, David Starr, Barton Warren Evermann, and Howard Walton Clark

1930. Check list of the fishes and fishlike vertebrates of North and Middle America north of the northern boundary of Venezuela and Colombia. Rept. U. S. Comm. Fish. (1928), Appendix 10 (Bur. Fish. Doc. 1055), iv + 670 p.

Jordan, David Starr, and Henry W. Fowler

1902. A review of the Chaetodontidae and related families of fishes found in the waters of Japan. Proc. U. S. Natl. Mus. (1903), 25(1296): 513-563, figs. 1-6.

Klunzinger, C. B.

1880. Die v. Müller'sche Sammlung australischer Fische in Stuttgart. Sitzungsberichte der Mathematisch-Naturwissenschaftlichen Classe der Kaiserlichen Akademie der Wissenschaften, 80(1): 325-430, pls. 1-8.

Longley, William H., and Samuel F. Hildebrand

1941. Systematic catalogue of the fishes of Tortugas, Florida. Carnegie Inst. Wash. Pub. 535, Pap. Tortugas Lab., 34: i-xiii, 1-331, pls. 1-34.

Lowe, Richard Thomas

1843. Notices of fishes newly observed or discovered in Madeira during the years 1840, 1841, and 1842. Proc. Zool. Soc. London, 11: 81-95.

Matsubara, Kiyomatsu

1955. Fish morphology and hierarchy. Ishizaki-Shoten, Tokyo, pt. II, p. I-V, 791-1605, figs. 290-536; pt. III, p. I-XIII, pls. 1-135.

McCulloch, Allan R.

1915. Report on some fishes obtained by the F. I. S. "Endeavour" on the coasts of Queensland, New South Wales, Victoria, Tasmania, South and South-Western Australia, Part. III. Biol. Res. "Endeavour," 3 (pt. 3): 97-107, pls. XV-XXXVII.

1929. A check-list of the fishes recorded from Australia. Memoir Australian Mus., Sydney, no. 5, part I, p. 1-144.

Meyer, A. B.

1885. Catalogo de los peces recolectados en el archipelago de las Indias orientales durante los anos 1870 a 1873. Anales de la Sociedad Espanola de Historia Natural (Madrid), 14: 5-49.

Miranda Ribeiro, Alipio de

1903. Pescas do "Annie." A Lavoura, an. 7(4/7) Abril a Julho, p. 150-196. (not seen)

1915. Fauna Brasiliense. Peixes. Archivos do Museu Nacional do Rio de Janeiro, 17(pt. 1): section on Caproidae (pages not numbered).

1918. Fauna Brasiliense (Peixes). Tomo V. Eleutherobranchios, Aspirophores. Physoclisti. Archivos do Museu Nacional do Rio de Janeiro, 21: 7-277.

Müller, Johannes, and Franz Herrmann Troschel

1849. Horae ichthyologicae. Beschreibung und Abbildung neuer Fische. Veit, Berlin, pt. 3.

Noronha, Adolfo Cesar, and Alberto Artur Sarmento

1948. Vertebrados da Madeira. 2. Volume. Peixes. Junta Geral do Distrito Autonomo do Funchal, 2nd Ed., p. 1-181.

Ogilby, J. Douglas

1910. On some new fishes from the Queensland coast. Proc. Roy. Soc. Queensland, 23: 85-139. (not seen)

Osorio, Balthazar

1909. Contribuicao para o conhecimento da fauna bathypelagica visinha das costas de Portugal. Memorias do Museu Bocage, Lisboa, no. 1, p. 1-121, pls.

Poll, Max

1954. Poissons. IV.—Teleosteens Acanthopterygiens (Premiere Partie). Resultats Scientifiques. Expedition Oceanographique Belge dans les Eaux Catieres Africaines de l'Atlantique Sud (1948-1949), Bruxelles, p. 1-390, figs. 1-107, pls. I-IX.

Raney, Edward C., and Robert D. Ross

1947. Record of the zeiform fish, *Antigonia capros*, from the Atlantic off Block Island. Copeia, 1947(1): 63-64.

Regan, C. Tate

1910. The anatomy and classification of the teleostean fishes of the order Zeomorphi. Ann. Mag. Nat. Hist., Ser. 8, 6: 481-484.

Roule, Louis

1919. Poissons provenant des campagnes du yacht *Princesse-Alice* (1891-1913) et du yacht *Hirondelle II* (1914). Resultats des Campagnes Scientifiques Accomplies sur son Yacht par Albert Ier Prince Souverain de Monaco, no. 52, p. 1-190, pls. I-VII.

Salzen, E. A.

1957. A trawling survey off the Gold Coast. Journal du Conseil, 23(1): 72-82, figs. 1-2.

Springer, Stewart, and Harvey R. Bullis, Jr.

1956. Collections by the *Oregon* in the Gulf of Mexico. List of crustaceans, mollusks, and fishes identified from collections made by the exploratory fishing vessel *Oregon* in the Gulf of Mexico and adjacent seas 1950 through 1955. U. S. Fish & Wildlife Serv., Spec. Sci. Rept.: Fish. No. 196, p. 1-134.

Starks, Edwin Chapin

1902. The relationship and osteology of the caproid fishes or Antigoniidae. Proc. U. S. Natl. Mus. (1903), 25(1297): 565-572, figs. 1-3.

Temminck, C., and H. Schlegel

1884. Pisces, (In) Siebold, P. F. Fauna Japonica. Tokyo (1934 reprint), p. 1-345, pls. 1-142, 1 supl.-pl.

Thompson, D'Arcy Wintworth

1943. On growth and form. Univ. Press, Cambridge, New Ed., 1116 p., figs. 1-554.

Tortonese, Enrico

1943-48. Il Caprisco (*Capros aper* L.) e le sue relazioni con gli altri Pesci Teleostei. Bollettino dell'Istituto e Museo di Zoologia dell'Universita di Torino, 1(11): 137-149, figs. 1-3.

Uchida, K.

1936. A note on the pelagic postlarval stages of *Antigonia rubescens* (Pisces, Capriformes). [In Japanese, English summary] Dobutsugaku Zasshi (Tokyo), 48: 935-939, 2 figs. (not seen)

Weber, Max

1913. Der Fische der Siboga-Expedition. E. J. Brill, Leiden, xii + 710 p., figs. 1-123, pls. I-XII.

Weber, Max, and L. F. de Beaufort

1929. The fishes of the Indo-Australian Archipelago. V. Anacanthini, Allotriognathi, Heterosomata, Berycomorphi, Percomorphi. Leiden, E. J. Brill, xiv + 458 p., figs. 1-98.

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A NEW SPECIES OF THE BOARFISH GENUS *ANTIGONIA* FROM THE WESTERN ATLANTIC

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Specimens of boarfish of the genus *Antigonia* from the Western Atlantic that we have examined comprise two taxonomically distinct and variable forms. One of these is identified as *Antigonia capros* Lowe. This species fits the classical concept of *Antigonia* in having body depth generally greater than or equal to the standard length. The second form has body depth generally less than the standard length. It is described here as a new species.

The following description is in part extracted from a manuscript that has been accepted for inclusion in the Bulletin of the Florida State Museum, but that has been delayed in publication. The subsequent publication will contain biological data and more complete descriptions of the two Western Atlantic species of *Antigonia* and their relationships to each other and to nominal species of *Antigonia* from the Indo-Pacific. Paratypes have been distributed to or identified in the collections of the several museums listed below, and the description of the new species is published at this time to make the name available.

ANTIGONIA COMBATIA, new species

(Figure 1)

Diagnosis: [3] An *Antigonia* with dorsal spines 9 (rarely 10), dorsal softrays 29 (26 to 30), anal softrays 27 (23 to 28), pectoral I-12 (rarely I-11 or I-13), scale rows 53 (about 49 to 57), body depth 66.7 (100.8 to 62.4), third (longest) dorsal spine length 16.2 (30.2 to 16.2), first (longest) anal spine length 7.7 (16.2 to 7.7), pelvic spine length 12.4 (22.6 to 12.4), upper jaw length 9.0 (8.1 to 11.1).

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[2] Fishery Methods and Equipment Specialist, Gulf Fishery Exploration and Gear Research, Pascagoula, Mississippi.

[3] The number after each character is the value recorded for the holotype. Numbers in parentheses following this are ranges in values of all specimens. Where the proportion decreases with growth, the larger extreme of the range is placed first. Body proportions are in percent of standard length (% S.L.). This procedure is followed in the Description.

Contribution No. 34
U. S. Fish & Wildlife Service
Bureau of Commercial Fisheries
Biological Laboratory
Brunswick, Georgia

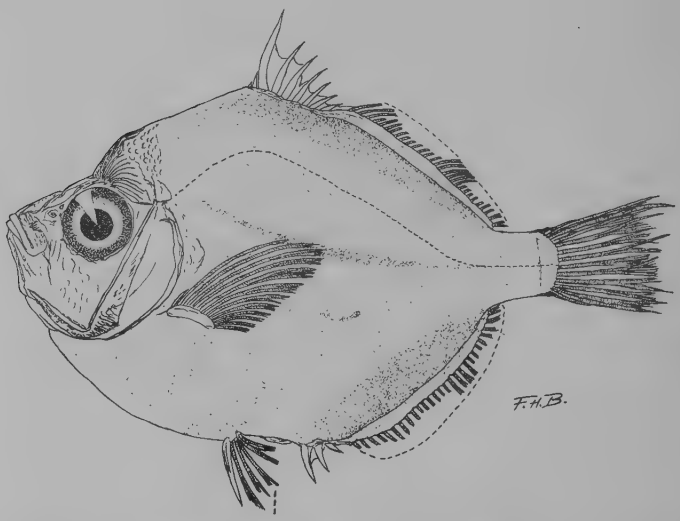

Figure 1. *Antigonia combatia*, holotype, USNM 159597, 117 mm. in standard length, *Combat* sta. 259, 24°29′ N., 83°28′ W., southwest of Tortugas, Florida.

Description: Body compressed and elevated. Greatest vertical body depth, 66.7 (100.8-62.4). Snout to 1st dosal spine, 50.0 (69.4-50.0). Snout to 1st anal spine, 68.8 (84.5-66.7). Depth of peduncle at caudal base, 12.0 (16.2-11.9).

Head length, 34.2 (43.4-34.2). Profile changing with growth; generally with an apex produced by upper end of supraoccipital crest, and concavities between apex and dorsal fin origin and between apex and snout, these concavities varying with growth stage and individuals. Snout length, 10.3 (12.5-9.9). Cleft of mouth angular; lower jaw slightly projecting. Upper jaw length, 9.0 (8.1-11.1). Eye diameter, 13.2 (20.4-13.2).

Gill rakers, 5 (3-5) + 16 (14-16). Branchiostegals, 6. Scale rows, 53 (about 49 to 57).

Dorsal spines, 9 (9-10); third spine the longest, its length, 16.2 (30.2-16.2). Anal spines, 3 (3); first spine the longest, its length, 7.7 (16.2-7.7). Dorsal spines connected to dorsal softrays and anal spines to anal softrays each by a shallow notched membrane. Dor-

sal softrays, 29 (26 to 30; modally, 28). Anal softrays, 27 (23 to 28; modally, 26). Anal fin base length, 44.4 (55.2-40.7). Caudal fin subtruncate; caudal principal rays, 6 + 6; caudal secondary rays, 4 + 3. Pectoral fin bluntly pointed; pectoral rays, I-12 (rarely, I-11 or I-13); pectoral length, 29.1 (40.4-28.5). Pelvic fin pointed; pelvic rays, I-5 (I-5); pelvic spine length, 12.4 (22.6-12.4).

Pigmentation essentially faded out on preserved specimens. A Kodachrome slide taken of several paratypes immediately after capture shows the dorsal aspects of the head and body to be reddish pink blending into pink on the sides and then into silver on the ventrolateral aspects.

Relationships: Because the relationships of the nominal species of *Antigonia* are presently uncertain and significant data on the intraspecific variations of only two of them (*A. combatia* and *A. capros*) are available, *A. combatia* is distinguished below from each of the nominal species by the characters we consider most significant. *A. combatia* differs from *A. capros* Lowe, *A. aurora* (Müller and Troschel), *A. steindachneri* Jordan and Fowler, *A. browni* Fowler, and *A. eos* Gilbert in having fewer dorsal and anal softrays (31 or more dorsal and 29 or more anal softrays in the other species) and in having a shorter pelvic spine (24 percent of standard length or greater in the other species). *A. combatia* and the remaining nominal species have generally similar numbers of dorsal and anal softrays. *A. combatia* differs from *A. rubescens* (Günther) and *A. fowleri* Franz in having a greater number of oblique scale rows (38 to 47 rows in *A. rubescens* and *A. fowleri*), and in having a shorter pelvic spine at comparable body sizes (from about 20 to 50 mm. S.L., 14 to 23% S.L. in *A. combatia*, 24 to 30% S.L. in the other species; above 50 mm. S.L., 12 to 20.9% S.L. in *A. combatia*, 21 to 26% S.L. in the other species). *A. combatia* differs from *A. rhomboidea* McCulloch in having a lesser body depth (about 106% S.L. in *A. rhomboidea*) and in having a shorter pelvic spine (about 26.4% S.L. in *A. rhomboidea*). *A. combatia* differs from *A. rubicunda* Ogilby in having a shorter 3rd dorsal spine (about 34% S.L. in *A. rubicunda*) and in having a shorter pelvic spine (about 28% S.L. in *A. rubicunda*). *A. combatia* differs from *A. malayanus* Weber in having one less dorsal spine (8 spines in all known specimens of *A. malayanus*) and in having a shorter upper jaw (about 12.5 to 14% S.L. in *A. malayanus*). [*Antigonia mulleri*

Klunzinger appears to belong to the family Zeidae. *Antigonia benhatatate* (Bleeker) is apparently a *nomen nudum*.]

Distribution: The holotype was taken off Tortugas, Florida. The paratypes were taken off Brazil (Amazon River), Surinam, British Guiana, Caribbean Nicaragua and Honduras, northern Cuba, Florida, North Carolina, and Massachusetts. Recorded depths of the trawl hauls in which most of the specimens were taken range from 65 to 325 fathoms.

Holotype: U. S. National Museum No. 159593, 117 mm. S.L., taken at COMBAT station 259, 24°29′ N., 83°28′ W., 7 March 1957.

Paratypes: Deposited in the following collections, U. S. National Museum; Chicago Natural History Museum; Academy of Natural Sciences of Philadelphia; Museum of Comparative Zoology; British Museum (Natural History); Museu Municipal do Funchal; Museu Nacional, Rio de Janeiro; Bingham Oceanographic Collection; University of Florida; Stanford University; Tulane University; University of Miami Marine Laboratory; Cornell University; Gulf Coast Research Laboratory; South Atlantic Fishery Investigations, Brunswick, Georgia. The 186 paratypes range in size from 118 to about 19 mm. S.L.

Derivation of the Name: Named for the M/V COMBAT, chartered by the U. S. Fish and Wildlife Service primarily for deepwater trawling exploration off the Atlantic coast of the southeastern United States. Collections made with this vessel are adding greatly to our biological knowledge of the area. COMBAT burned and sank off Mexico in December 1957.

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The Draconettidae A Review of the Family with the Description of a New Species*

John C. Briggs and Frederick H. Berry

THIS contribution was initiated by our attempt to identify a strange, elongate, callionymid-like fish recently taken by the U.S. Fish and Wildlife Service vessel *Combat* off the east coast of Florida just beyond the edge of the Continental Shelf.

The only description in the literature that seemed to fit our specimen was of *Draconetta acanthopoma* Regan (1904:130). This tentative identification was verified through supplementary information provided by Dr. Denys W. Tucker, who kindly re-examined the type (the only known specimen) in the British Museum (Natural History). In his brief original description, Regan (*loc. cit.*) gave the locality of capture as simply "the North Atlantic" but did state that the individual was sent to the British Museum by the Smithsonian Institution as an example of *Callionymus himantophorus* Goode and Bean. Fortunately, along with the type, Dr. Tucker found a tag bearing the number 45752. This was then traced, through the help of Dr. Ernest A. Lachner, to a jar in the U. S. National Museum containing a collection, originally labeled *Callionymus himantophorus*, taken by the *Albatross* at 30°47′30″N., 79°49′00″W. from 270 fathoms on May 5, 1886. Thus, some 54 years after the original description, we are able to provide information about the type locality and date of collection for the species *Draconetta acanthopoma* Regan. These data, and those provided by the additional specimens reported on in this paper, give the first definite New World record for this rare percomorph family (Draconettidae).

A search of other *Combat* fish collections produced 22 additional specimens of *D. acanthopoma*, and two more *Albatross* individuals were found in the U.S. National Museum. This enables us to give a relatively detailed description of this species plus some information about its range.

Before this material was ready for publica-

* Contribution No. 38, U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Biological Laboratory, Brunswick, Georgia.

tion, the U.S. Fish and Wildlife Service vessel *Oregon* returned from an exploratory fishing trip off the coast of northeastern South America. Dr. Giles W. Mead called out attention to the presence of a form of *Draconetta* at the U.S. National Museum in some of the collections from that cruise. These and other individuals from the *Oregon* cruise proved to be an undescribed species of *Draconetta* represented by a total of 63 specimens.

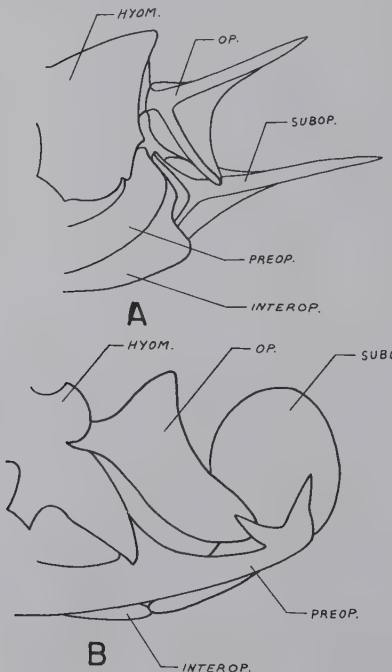

Fig. 1.—Opercular region. A, *Draconetta oregona*. B, *Callionymus himantophorus*. HYOM., hyomandibular; OP., opercular; PREOP., preopular; INTEROP., interopercular; SUBOP., subopercular.

With such adequate material, certain aspects of the osteology of the two species were investigated with the intended purpose of clarifying the relationship of the Draconettidae with the Callionymidae. A study of the external morphology alone had given rise to some feeling of doubt about the usual familial separation of *Draconetta*, but this was resolved upon examination of the cleared and stained specimens. The following abbreviations are used under the accounts of species in the text: ANSP, Academy of Natural Sciences of Philadelphia; CNHM, Chicago Natural History Museum; MCZ, Museum of Comparative Zoology, Harvard; SAFI, South Atlantic Fishery Investigations, Brunswick; SU, Natural History Museum, Stanford; TU, Tulane University, New Orleans; UBC, University of British Columbia, Vancouver; UF, University of Florida, Gainesville; USNM, United States National Museum, Washington, D. C.

Family Relationships

The most widely used general fish classification at present is that of Berg (1947). He includes the families Draconettidae and Callionymidae in a separate suborder equivalent to Regan's (1913:144) "Division Callionymiformes." Unfortunately, Berg had no new information about either family and based his description of the suborder upon such information as was available in the literature.

Regan (*loc. cit.*) had a single specimen of *Draconetta* (*D. acanthopoma*) at hand but no skeletal material of this genus. Apparently, all of Starks' (1923:267; 1926:301; 1930:222) findings were based on a skeletal preparation of *Callionymus valenciennesi* Temminck and Schlegel, and Gregory (1933:362) examined only a skull of *C. lyra* Linnaeus. Consequently, Berg's (1947:481) osteological analysis of his suborder Callionymoidei is based only on Regan's sparse early work plus the more recent literature descriptions of two species belonging to the genus *Callionymus*. In view of this, it is not surprising that our examination of cleared and stained preparations of the two Atlantic species of *Draconetta* has revealed the need for some major changes in Berg's analysis.

As Regan (1913:145) has pointed out, the Draconettidae may be distinguished by some obvious external differences: the preoperculum is entire while the operculum and suboperculum bear strong spines (Fig. 1 A). In *Callionymus* the preoperculum is produced posteriorly as a very strong spine (Fig. 1 B) which may have various kinds of points and shapes, depending on the species; and the opercular and subopercular elements are moderately developed, rounded, and bear no armature.

Gregory (1933:361) found that in *Callionymus lyra* the ascending processes of the premaxillae are received posteriorly into a deep fossa formed chiefly by the lateral ethmoids. Berg (1947:481), with a change in nomenclature, applied this characteristic to the en-

ire suborder. However, we find no indication of such a modification in *Draconetta*.

Starks (1923:268; 1930:222) discovered that he supracleithrum was missing in *Callionymus valenciennesi* Temminck and Schlegel, and he provided a figure (1930, fig. 32) of the pectoral girdle which showed a total of three radials suturally joined to one another. Berg (*op. cit.*) also utilized these characteristics for he suborder Callionymoidei, and, in so doing, followed Gregory's misinterpretation of Starks' drawing saying that the scapula formed a bridge between the three expanded radials. However, in both *Draconetta* and *Callionymus himantophorus* the supracleithrum is rather simple compared to the heavier, plate-like structures (Fig. 3 B) found in *Callionymus*.

Considering the paucity of our knowledge about these two families and their relationships with other percomorph groups, we see no present need for setting them aside in a separate suborder. Their morphology is no more peculiar than that of several other families which are traditionally retained without subordinal recognition within the vast assemblage of the Percomorphi.

On the basis of our examination of the *Draconetta* specimens and a direct comparison with *Callionymus himantophorus*, we be-

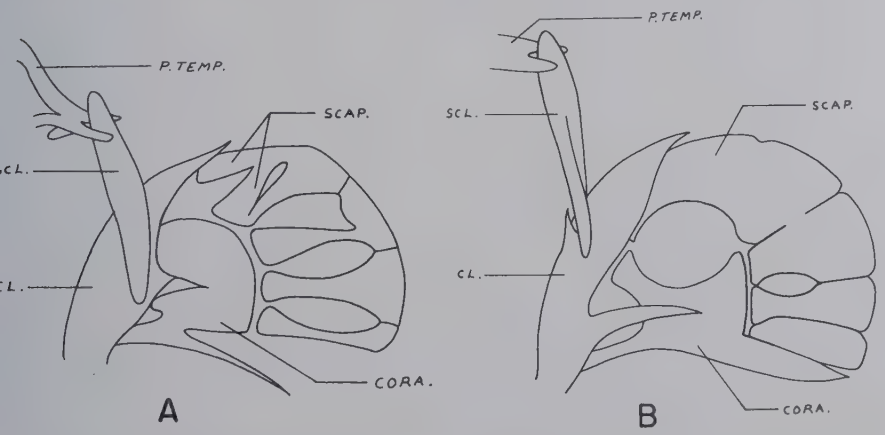

Fig. 2.—Pectoral girdle. A, *Draconetta oregona*. B, *Callionymus himantophorus*. CL., cleithrum; CORA., coracoid; P. TEMP., postemporal; SCL., supracleithrum; SCAP., scapula.

present and well developed, and in neither does the scapula form a bridge between the radials. In addition, four radials, widely separated by foramina, are apparently recognizable in *Draconetta* (Fig. 2 A). In *Callionymus himantophorus*, the radials have been reduced to three (Fig. 2 B), presumably by fusion of the uppermost element to the scapula. It also should be noted (Fig. 2 B), that the latter species possesses a single large interradial foramen.

Regan (1913:145) stated that the Callionymidae possessed 21 vertebrae, and Starks (1923:269) observed that the vertebral column was peculiar in that the neural and haemal spines were plate-like. These characters were also used by Berg (*op. cit.*) to define the suborder, but they are not characteristic of the Draconettidae. Our cleared and stained specimens of *Draconetta* revealed 23 vertebrae and

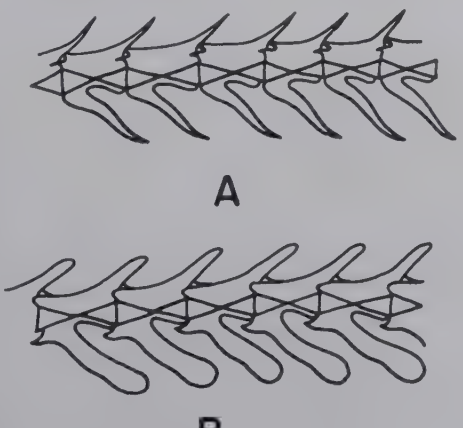

Fig. 3.—Section of caudal vertebral column. A, *Draconetta oregona*. B, *Callionymus himanto-*

lieve that these genera do represent distinct, but closely related, families. They may now be best defined as follows:

Family Callionymidae[1]

Gill opening reduced to a small foramen on upper side of head; operculum and subopercular entire; preoperculum bearing a very strong spine; anterior cranial bones forming a deep groove for the receipt of the ascending processes of the premaxillaries; three radials in pectoral girdle closely joined to one another; 21 vertebrae with neural and haemal spines plate-like and split at the ends for articulation with the dorsal and anal pterygiophores; dorsal fin spines usually 4; dorsal fin soft rays 6 to 11; anal fin soft rays 4 to 10.

Family Draconettidae

Gill opening comparatively broad, extending from a point about opposite upper pectoral edge to just above pelvic base; operculum and suboperculum each bearing a strong straight spine; preoperculum entire; anterior cranial bones not forming a deep groove for the receipt of the ascending processes of the premaxillaries; four radials in pectoral girdle separated by large foramina; 23 vertebrae with neural and haemal spines of normal shape and not articulating directly with the dorsal and anal pterygiophores; dorsal fin spines 3; dorsal fin soft rays 12 to 15; anal fin soft rays 12 to 13.

Aside from the bones of the opercular series (which are difficult to evaluate in terms of relative specialization), the general morphology of the Draconettidae indicates that it is the most primitive of the two families and, perhaps, should be considered close to the ancestral line of the Callionymidae. Such characteristics as the large gill opening, unmodified anterior cranial bones, four pectoral radials, a larger number of vertebrae with unspecialized spines, a greater number of dorsal and anal fin rays, and a larger over-all size, are suggested as evidence of a relatively primitive status for the Draconettidae.

Genus *Draconetta* Jordan and Fowler

Draconetta Jordan and Fowler, 1903, p. 939 (type species *Draconetta xenica* Jordan and Fowler, 1903, by original designation).

Centrodraco Regan, 1913, p. 145 (type species *Draconetta acanthopoma* Regan, 1904, by original designation).

Artificial Key to the Species of Draconetta

1a. Pectoral fin rays 16 ..... *pseudoxenica* (p. 126).

1b. Pectoral fin rays 20–27.

2a. Dorsal soft rays 12, anal soft rays 12 ..... *xenica* (p. 127).

2b. Dorsal soft rays 14–15, anal soft rays 13.

3a. Caudal peduncle relatively deep, 6.3–7.4 percent of standard length; first dorsal spine 4.9–6.4 percent of standard length; lateral line extending posteriorly to below 6th to 7th dorsal soft ray; dark rounded spots and blotches on side of body; no sexual dimorphism ..... *acanthopoma* (p. 127).

3b. Caudal peduncle relatively slender, 4.7–6.1 percent of standard length; first dorsal spine 6.9–19.7 percent of standard length; lateral line extending posteriorly to below 10th to 12th dorsal soft ray; narrow longitudinal dark spots on side of body; marked sexual dimorphism ..... *oregona* (p. 129).

Draconetta pseudoxenica Kamohara

Draconetta pseudoxenica Kamohara, 1952, p. 88, fig. 86 (Mimase, Prov. Tosa).—Matsubara, 1955, p. 710 (key to Japanese species of *Draconetta*).

Diagnosis.—A *Draconetta* with a light reddish base color, paler below; back spotted with greenish; base of pectoral red. The following measurements are given as a percentage of standard length: First dorsal spine 4.2, second dorsal spine 7.9, third dorsal spine 4.7, first dorsal soft ray 14.2, longest dorsal soft ray (the second) 14.7, first anal soft ray 5.8, longest anal soft ray (the ninth) 8.4, pectoral fin length 22.1, and pelvic fin length 21.0. Dorsal III-14; anal 13; pectoral 16.

Relationship.—Probably most closely related to *Draconetta xenica* but its reduced number of pectoral rays plus its more numerous dorsal and anal rays allow it to be easily distinguished.

Remarks.—This species is known only from

[1] This family is much in need of revision, and, since this characterization is based mostly upon our knowledge of the genus *Callionymus*, it is quite likely that our definition of this family may be expanded or altered with such revision.

he holotype deposited in the Biological Labo-ory of the Kôchi Kôtô Gakkô.

Range.—Mimase, Tosa Bay, Japan.

Draconetta xenica Jordan and Fowler

Draconetta xenica Jordan and Fowler, 1903, p. 939, fig. 1 (Suruga Bay at 100 fathoms).—Jordan and Starks, 1904, p. 589, fig. (reference to same specimen).—Kamohara, 1952, p. 88 (Mimase, Prov. Tosa).—Matsubara, 1955, p. 710.

Draconetta hawaiiensis Gilbert, 1905, p. 652, pl. 91 (channel between Molokai and Maui at 122–132 fathoms).—Jordan and Seale, 1906, p. 415 (reference to same specimen).—Fowler, 1928, p. 422 (reference to same specimen).

Diagnosis.—A *Draconetta* with a pale brown base color; back and side mottled and spotted with dark brown; a blackish band extending from base of spinous dorsal to behind pectoral base; spinous dorsal blackish. The following measurements are given as percentages of standard length: First dorsal spine 14.8–20.6, second dorsal spine 12.5–17.8, third dorsal spine 10.3–15.5, first dorsal soft ray 13.2–19.6, longest dorsal soft ray (10th) about 20.6, first anal soft ray 7.4–8.2, longest anal soft ray (8th) 13.4–14.0, pectoral fin length 20.6–26.7, and pelvic fin length 22.7–24.0. Dorsal III-12; anal 12; pectoral 20–23.

Relationship.—Seems to be closest to *Draconetta pseudoxenica* but has more pectoral rays and fewer dorsal and anal rays.

Remarks.—This species is known only from three specimens, the holotype of *D. xenica* deposited in the U. S. National Museum (No. 50816), the holotype of *D. hawaiiensis* at the same institution (No. 51633), and an individual reported by Kamohara (1952:88) in the Biological Laboratory of the Kôchi Kôtô Gakkô.

Range.—Japan to Hawaii.

Draconetta acanthopoma Regan

Figure 4

Draconetta acanthopoma Regan, 1904, p. 130 (the North Atlantic).—Jordan, Evermann and Clark, 1930, p. 450 (North Atlantic, in deep water).

Centrodraco acanthopoma Regan, 1913, p. 145 (the North Atlantic).

Diagnosis.—A *Draconetta* with a distinctive color pattern consisting of rounded spots and blotches on the side of the body. Lateral line fine, extending from the upper attachment of the gill membrane posteriorly to a position below the 6th to 7th dorsal soft ray. Caudal peduncle relatively deep, 6.3–7.4 percent of standard length. First dorsal spine 4.9–6.4 percent of standard length (Fig. 5). Longest anal soft ray (usually the 13th) 8.0–10.4 percent of standard length. No externally apparent sexual dimorphism. Dorsal III-14 to 15; anal 13; pectoral 25–26.

Description.—The following measurements are given as a percentage of standard length: Head length 32.4–36.8, eye diameter 11.4–15.2, snout length 7.7–9.4, upper jaw length 8.5–10.0, body depth at pelvic origin 12.6–16.9, snout to pectoral origin 31.1–35.8, snout to pelvic origin 27.1–30.7, snout to first dorsal spine 32.3–36.8, snout to first anal soft ray 51.8–55.6, body depth at first anal soft ray 10.9–14.1, second dorsal spine 8.6–10.1, third dorsal spine 4.7–6.8, first dorsal soft ray 10.3–13.6 (Fig. 6), longest dorsal soft ray (usually the 3rd) 12.1–13.6, pectoral fin length 22.9–27.2, pelvic fin length 22.3–31.1.

External sexual dimorphism is not apparent in our specimens which range from 47.5 to 99 mm. standard length—its possible manifestation at larger sizes is presently indeterminate.

Coloration.—Dark rounded spots and irregular blotches on the side of the body; a few small spots on head and nape with a large rounded dark area on the operculum; a single rounded mass of dark pigment at the caudal base; all pigment very faded on some specimens; usually some melanophores scattered on the membranes of both the spinous and soft dorsal fins, but the interspinous membranes very dark on some specimens; the pectoral, anal, and pelvic fins unpigmented; a single fresh-caught specimen noted with scarlet body spots and light rose colored body.

Relationship.—Most closely related to the following species but readily separated from it by the characters listed in the diagnosis and the key to the species.

Range.—Off the east coast of the United States beyond the edge of the Continental Shelf at depths of 210 to 300 fathoms, from about 15 miles south of Key West, Florida, to about 45 miles east of Cumberland Island, Georgia.

Material Examined.—USNM 46105, 1 female, 72 mm. S.L., *Albatross* Sta. 2667, 30°53′ N., 79°42′30″W., about 45 miles east of Cumberland Island, Georgia, 273 fathoms, 5 May 1886.—USNM 45752, 1 specimen, 78 mm. S.L., *Albatross* Sta. 2666, 30°47′30″N., 79°49′W.,

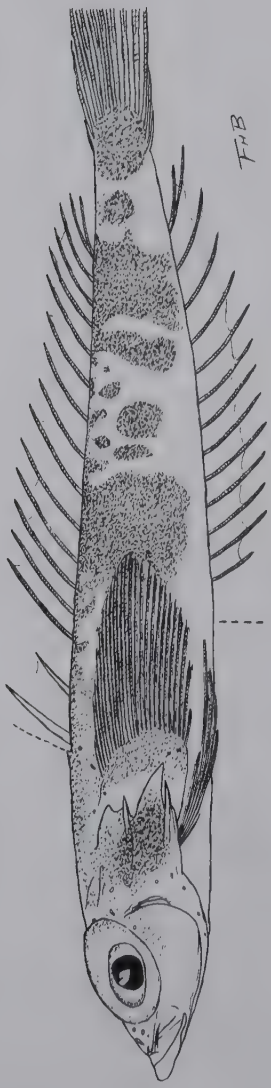

Fig. 4.—*Draconetta acanthopoma* Regan, female, 83 mm. standard length, USNM 156957.

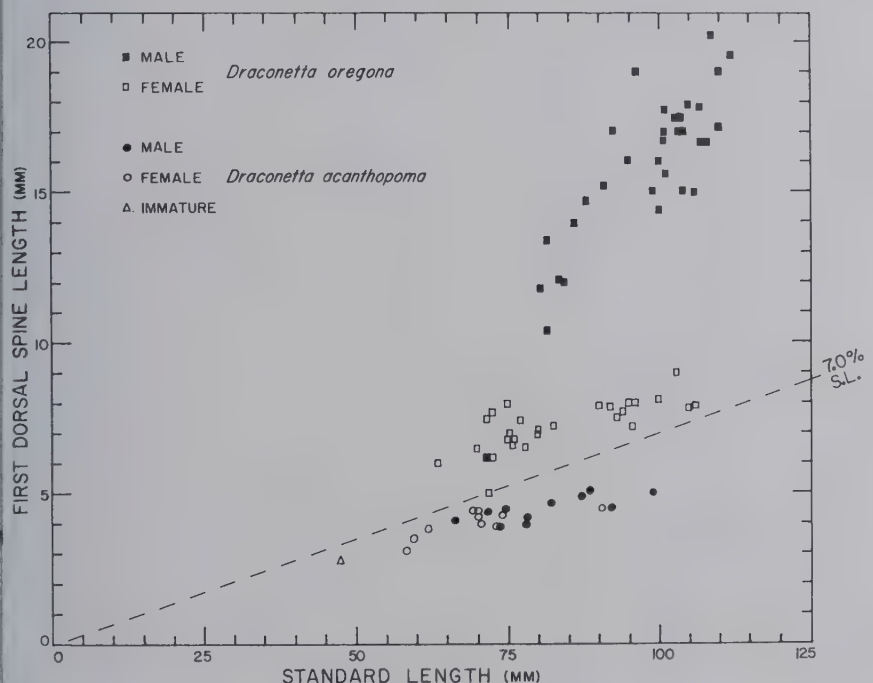

Fig. 5.—Relation of first dorsal spine length to standard length for *Draconetta oregona* and *Draconetta acanthopoma*.

bout 42 miles east of Cumberland Island, Georgia, 270 fathoms, 5 May 1886.—USNM 56957, 1 female, 83 mm. S.L., *Combat* Sta. 310, 30°40′N., 79°57′W., about 77 miles east of Fernandina, Florida, 210 fathoms, 24 April 1957.—USNM 156958, 1 male, 82 mm. S.L., *Combat* Sta. 439, 25°03′N., 80°01′W., about 20 miles southeast of Key Largo, Florida, 225 fathoms, 22 July 1957.—USNM 156956, 6 males, 71.5 to 99 mm. S.L., 4 females, 58 to 90.5 mm. S.L., and 1 immature specimen, 47.5 mm. S.L., *Combat* Sta. 436, 24°13′N., 81°42′W., about 15 miles south of Key West, Florida, 300 fathoms, 21 July 1957.—SAFI collection, 2 males (cleared and stained), 73.5 and 77 mm. S.L., *Combat* Sta. 436.—SAFI collection, 1 male, 88.5 mm. S.L., and 1 female, 74 mm. S.L., *Combat* Sta. 436.—UBC 58-308, 1 female, 73 mm. S.L., *Combat* Sta. 436.—CNHM 64460, 1 female, 70.5 mm. S.L., *Combat* Sta. 436.—UF 5246, 1 female, 70 mm. S.L., *Combat* Sta. 436.—SU 51107, 1 female, 70 mm. S.L., *Combat* Sta. 436.—ANSP 83825, 1 female, 69 mm. S.L., *Combat* Sta. 436.—MCZ 3990, 1 male, 66 mm. S.L., *Combat* Sta. 436.—TU collection, 1 male, 78 mm. S.L., *Combat* Sta. 436.

Draconetta oregona, *sp. nov.*

Figure 7

Diagnosis.—A *Draconetta* with a distinctive color pattern consisting mainly of narrow elongated spots on side of body. Lateral line fine, extending from the upper attachment of the gill membrane posteriorly to a position below the 10th to 12th dorsal soft ray. Caudal peduncle relatively narrow, 4.7–6.1 percent of standard length. First dorsal spine 6.9–19.7 percent of standard length (Fig. 5). Longest anal soft ray (usually the 13th) 10.7–13.9 percent of standard length. Externally apparent sexual dimorphism present. Dorsal III-14; anal 13; pectoral 23–27.

Description.—The following measurements are given as a percentage of standard length: Head length 33.6–38.0, eye diameter 10.2–13.3, snout length 7.9–10.0, upper jaw length 9.0–10.6, body depth at pelvic origin 11.2–14.8, snout to pectoral origin 32.4–35.5, snout

to pelvic origin 25.6–31.0, snout to first dorsal spine 30.9–35.5, snout to first anal soft ray 52.3–56.2, body depth at first anal soft ray 9.1–11.4, first dorsal spine 10.6–19.7 in males and 6.9–10.7 in females, second dorsal spine 7.2–10.9, third dorsal spine 4.4–7.7, first dorsal soft ray in males 18.6–50.5 and 12.4–15.8 in females (Fig. 6), longest dorsal soft ray (usually the first) in males 26.2–35.1 and 13.1–15.4 in females, pectoral fin length 22.6–27.6, pelvic fin length 24.6–35.0. Sexual differences in the soft ray lengths are apparent at 72.5 mm. standard length (size of the smallest male available) and in the spine lengths by 80 mm. standard length. These differences become quite accentuated at maturity (see Figures 5 and 6). This type of dimorphism is quite common in the Callionymidae.

Coloration.—Elongated longitudinal dark spots on the side of the body concentrated in two areas, one along the midline and one above and parellel to it; these tending on larger specimens to appear as interrupted stripes instead of spots; smaller, elongate, black spots distributed on the nape and on the side of the head; two more narrow longi-

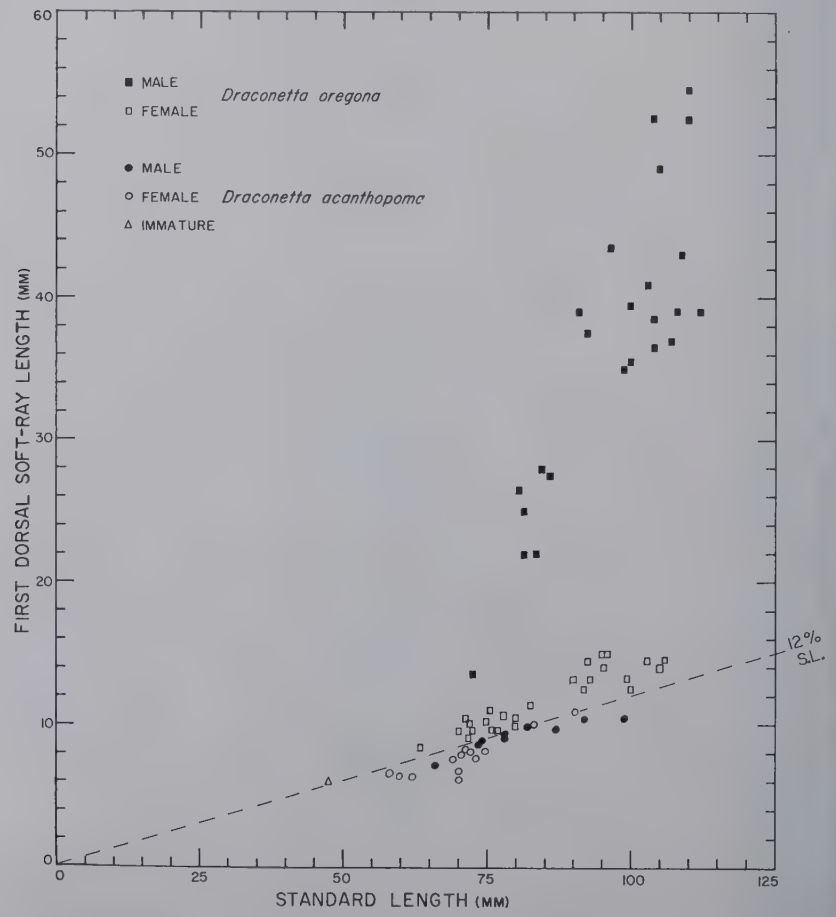

Fig. 6.—Relation of first dorsal soft ray length to standard length for *Draconetta oregona* and *Draconetta acanthopoma.*

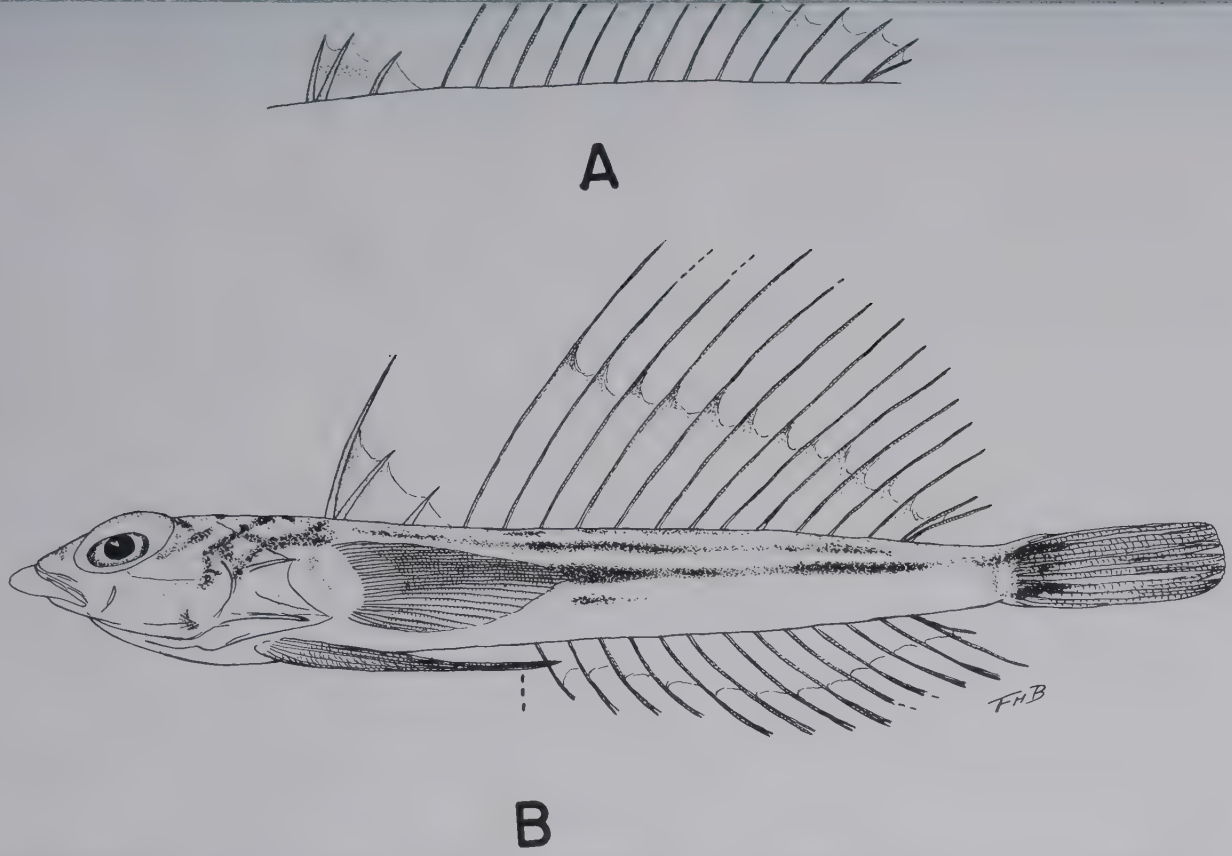

Fig. 7.- *Draconetta oregona*. A, dorsal fin of female, paratype, 105 mm. standard length, CNHM 64387. B, holotype, male, 112 mm. standard length, USNM 159776.

tudinal dark spots on the caudal base; usually a few melanophores scattered on the membranes of both the spinous and soft dorsal fins, but the interspinous membranes dark on some specimens; the pectoral, anal, and pelvic fins usually unpigmented, but the pelvics definitely pigmented on two large specimens.

Relationship.—Most closely related to *Dranetta acanthopoma* but readily separated from that species by the characters listed in the diagnosis and the key to the species.

Range.—Off the northeast coast of South America close to the edge of the Continental Shelf at depths of 125 to 225 fathoms.

Derivation of name.—This new species is named *oregona* to commemorate the important work of the U.S. Fish and Wildlife Service exploratory fishing vessel *Oregon* in contributing to the knowledge of Western Atlantic ichthyology.

Holotype.—USNM 159776, male, 112 mm. in standard length, *Oregon* Sta. 2080, 02°04′N., 47°00′W., about 160 miles northeast of mouth of Rio Para, Brazil, 125 fathoms, 17 November 1957.

Paratypes.—SAFI collection, 2 males, 72.5 and 109 mm. S.L., and 1 female, 72.5 mm. S.L. (all cleared and stained), collected with the holotype.—SAFI collection, 1 male, 104 mm. S.L., and 1 female, 92 mm. S.L., collected with the holotype.—TU 188831, 3 females, 90 to 106 mm. S.L., collected with the holotype.—SU 51106, 1 female, 103 mm. S.L., collected with the holotype.—UBC 58-307, 1 male, 101 mm. S.L., collected with the holotype.—UF 5245, 1 female, 95.5 mm. S.L., collected with the holotype.—ANSP 83826, 1 female, 99.5 mm. S.L., collected with the holotype.—MCZ 39989, 1 female, 95 mm. S.L., collected with the holotype.—UMML 3300, 2 males, 105 and 110 mm. S.L., and 1 female, 93 mm. S.L., collected with the holotype.—CNHM 64386, 3 males, 96.5 to 110 mm. S.L., and 3 females, 94 to 104 mm. S.L., collected with the holotype.—CNHM 64387, 1 male, 108 mm. S.L., and 1 female, 105 mm. S.L., *Oregon* Sta. 2081, 01°52′N., 46°54′W., 175 fathoms, 17 November 1957.—CNHM 64388, 5 males, 86 to 107 mm. S.L., and 4 females, 63.5 to 80 mm. S.L., *Oregon* Sta. 2082, 01°51′N., 46°50′W., 200 fathoms, 17 November 1957.—USNM 158875, 17 males, 72.5 to 107 mm. S.L., and 11 females, 70 to 82.5 mm. S.L., *Oregon* Sta. 2082.—CNHM 64389, 1 male, 106 mm. S.L., *Oregon* Sta. 2083, 01°49′N., 46°48′W., 225 fathoms, 17 November 1957.

Acknowledgments

We wish to thank especially three persons who kindly helped us assemble the information about this rare group of fishes: Giles W. Mead examined the types of *Draconetta xenica* and *D. hawaiiensis* at the U.S. National Museum, Denys W. Tucker examined the type of *D. acanthopoma* in the British Museum (Natural History), and Toshiji Kamohara sent us some additional information about the type of *D. pseudoxenica*. We also wish to express our appreciation to the following individuals and institutions for the loan of material: Harvey R. Bullis, Jr., U.S. Fish and Wildlife Service, Pascagoula, Miss.; C. Richard Robins, University of Miami; Leonard P. Schultz, U.S. National Museum; Royal D. Suttkus, Tulane University; Loren P. Woods, Chicago Natural History Museum. For propitious comments concerning the manuscript we thank William W. Anderson, David K. Caldwell, Jack W. Gehringer, and Giles W. Mead, U.S. Fish and Wildlife Service.

Literature Cited

Berg, L. S. 1947. Classification of fishes, both recent and fossil. *Translation from: Travaux de l'Institut Zoologique de l'Académie des Sciences de l'U.R.S.S. 1940, 5(2): 87–517, 190 figs.*

Fowler, H. W. 1928. The fishes of oceania. *Mem. Bernice P. Bishop Mus. 10: 1–539, 82 figs., 49 pls.*

Gilbert, C. H. 1905. Deep-sea fishes. *In* Jordan, D. S., and B. W. Everman, The Aquatic resources of the Hawaiian Islands, Part 2, Section 2. *Bull. U.S. Fish Comm. for 1903, 23: i–xi, 575–713, figs. 230–276, pls. 66–101.*

Gregory, W. K. 1933. Fish skulls: a study of the evolution of natural mechanisms. *Trans. Amer. Philos. Soc. New Series 23 (Art. 2): i–viii, 75–481, 302 figs.*

Jordan, D. S., and H. W. Fowler. 1903. A review of the dragonets (Callionymidae) and related fishes of the waters of Japan. *Proc. U.S. Nat. Mus. 25: 939–959, 9 figs.*

———, B. W. Evermann, and H. W. Clark. 1930. Check list of the fishes and fishlike vertebrates of North and Middle America north of the northern boundary of Venezuela and Colombia. *Rept. U.S. Comm. Fish. for 1928, (10): 1–670.*

———, and A. Seale. 1906. The fishes of Samoa. Description of the species found in the archipelago, with a provisional check-list of the fishes of oceania. *Bull. Bur. Fish. for 1905, 25: 173–455, 111 figs., pls. XXXIII–XXXVII, col. pls. XXXVIII–LIII.*

———, and E. C. Starks. 1904. List of fishes dredged by the steamer *Albatross* off the coast of Japan in the summer of 1900, with descriptions of new species and a review of the Japanese Macrouridae. *Bull. U.S. Fish. Comm. for 1902, 22: 577–630, text-figs., 8 pls.*

AMOHARA, T. 1952. Revised descriptions of the offshore bottom-fishes of Prov. Tosa, Shikoku, Japan. *Repts. Kochi Univ., Nat. Sci. (3): 1–122, 100 figs.*

ATSUBARA, K. 1955. Fish morphology and hierarchy, Part 1. *Ishizaki-Shoten, Tokyo, 789 pp., 289 figs. (in Japanese).*

EGAN, C. T. 1904. On the affinities of the genus *Draconetta*, with description of a new species. *Ann. Mag. Nat. Hist., Ser. 7, 14: 130–131.*

———. 1913. The classification of the percoid fishes. *Ann. Mag. Nat. Hist., Ser. 8, 12(67): 111–145.*

STARKS, E. C. 1923. The osteology and relationships of the uranoscopid fishes. *Stanford Univ. Publ., Biol. Sci. 3(3): 261–290.*

———. 1926. Bones of the ethmoid region of the fish skull. *Stanford Univ. Publ., Biol. Sci. 4(3): 139–338, 58 figs.*

———. 1930. The primary shoulder girdle of the bony fishes. *Stanford Univ. Publ., Biol. Sci. 6(2): 149–239, 38 figs.*

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12. Fish Schooling: A Possible Factor in Reducing Predation

This paper considers the possibility that fish schooling is a mechanism for protection against predation. There are two factors operating at cross-purposes: Regarding a single fish as a group of size one, schooling (a) reduces the number of groups and consequently the chance of detection, and (b) increases the size of groups, thus increasing the chance of detection. A third factor which may give an advantage to schooling is the limitation of capacity of the predator.

An expression is developed for the probabilities that a predator sights (and therefore eats) a nonschooled forage fish and a schooled forage fish. From these probabilities, an expression is found for the expected number of forage eaten when they school and when they do not school. Other things being equal, if the expected number of schooled forage eaten is less than the expected number of nonschooled forage eaten, then schooling is advantageous to the forage.

Since the number of forage a predator can eat is never more than the number present but may be less, the formulae can be simplified somewhat, leaving the advantage or disadvantage to forage through schooling as an inequality of probabilities. The probability distributions of the variates are found so that the probabilities in the inequality may be evaluated; such probabilities depend on four constants: average distance between predator and forage, standard deviation of this distance, sight range of the predator, and a size measure of a school of forage.

It is shown that for any reasonable values of these constants, the probability of detecting any particular forage fish is approximately the same whether it is schooled or not so that the meaningful consideration in the number of forage eaten when schooled vs. when not schooled is the reduced frequency of the predator's encounter with schooled forage. For example, if the predator meets 70 forage a week and can hold 10 at one feeding, he eats optimally if he finds 10 nonschooled forage a day; however, he may starve if he finds one school of 70 in the week, at which time he can hold only 10. Thus the meaningful factors in schooling advantage are (1) predator capacity, (2) the period of association of predator and school, and (3) school size. It is shown that as the number of forage fish in a school increase (total forage held constant), the consumption rate of forage by the predator will decrease.

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ON THE STATUS OF THE ATLANTIC LEATHERBACK TURTLE, *DERMOCHELYS CORIACEA CORIACEA*, AS A VISITANT TO FLORIDA NESTING BEACHES, WITH NATURAL HISTORY NOTES [1]

David K. Caldwell [2]
United States Fish and Wildlife Service

Carr (1952: 451) reported the first reliable record of the nesting of the Atlantic leatherback turtle, *Dermochelys coriacea coriacea* (Linnaeus), on North American mainland beaches during the past 100 years. Since that record, a second (Caldwell, Carr, and Hellier, 1956: 279) and a third (Allen and Neill, 1957: 144) have been published. In noting their second nesting record, Caldwell, Carr, and Hellier (1956: 283) remarked that each year a few nesting leatherbacks were reported to conservation agents in South Florida. These reports were of interest because biologists have always believed that the Atlantic leatherback is a rare and irregular visitor to North American beaches, if indeed it nests here at all.

New records, made available through the alert cooperation of Robert S. Pfister, James R. Pearce, and Rolland C. Byrd, agents for the Florida State Board of Conservation, now show that this turtle, while nesting rarely in Florida in comparison with the Atlantic loggerhead turtle, *Caretta caretta caretta* (Linnaeus), actually emerges regularly to nest on the beaches of the south Atlantic coast of Florida. There are 11 such records for 1957. A summary of these and the earlier records is presented in Table 1.

In addition to the nesting records, a few related natural history notes were made available.

Apparently the only instance in which the number of eggs deposited by a leatherback nesting in Florida was known is that cited by Carr (1952: 451) in which the turtle nesting at Flagler Beach (Table 1) was reported to have laid 80 eggs. Agent Pearce reported that the turtle shown in Table 1 as laying on May 30 had

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[2] Fishery Research Biologist, South Atlantic Fishery Investigations, Brunswick, Georgia (At the time of this study, Research Assistant, University of Florida, for the above grant).

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TABLE 1. SUMMARY OF RECENTLY OBSERVED NESTING ACTIVITY OF THE ATLANTIC LEATHERBACK TURTLE, *DERMOCHELYS C. CORIACEA*, IN FLORIDA

Date	Locality	Nature of Observation	Authority
June 6, 1947	Flagler Beach, Flagler Co.	Nesting turtle	Carr, 1952
Summer, ca. 1954	Ft. Pierce, St. Lucie Co.	Nesting turtle	Pfister, this paper
ca. July 15, 1955	Hutchinson's Island, Martin Co.	Track	Caldwell, Carr, and Hellier, 1956
July, 1955	Miami Beach, Dade Co.	Hatchlings on beach	Allen and Neill, 1957
ca. July 26, 1956	Hutchinson's Island, Martin Co.	Nesting turtle	Pfister, this paper
ca. April 15, 1957	Ft. Pierce, St. Lucie Co.	Track	Pfister, this paper
ca. April 15, 1957	Ft. Pierce, St. Lucie Co.	Track	Pfister, this paper
April 30, 1957	St. Lucie Co.	Track	Pfister, this paper
May 6 or 7, 1957	St. Lucie Co.	Nesting turtle	Pfister, this paper
May 17, 1957	Hutchinson's Island, Martin Co. (6½ mi. S. of Ft. Pierce Inlet)	Nesting turtle (Carcass)	Caldwell and Hellier, this paper
May 22, 1957	Hutchinson's Island, Martin Co. (4 mi. S. of Ft. Pierce Inlet)	Nesting turtle (est. 800 lbs.)	Pfister, this paper
May 27, 1957	Jupiter Island, Martin Co.	Track	Caldwell and Hellier, this paper
May 30, 1957	Jupiter Island, Martin Co.	Nesting turtle	Pearce, this paper
June 8, 1957	Indian River Co.	Track	Pfister, this paper
June 11, 1957	Juno Beach, Palm Beach Co.	Nesting turtle	Pearce, this paper
July 10, 1957	Juno Beach, Palm Beach Co.	Nesting turtle	Pearce, this paper

deposited 127 eggs in a three-foot-deep nest. He said the carapace of this individual measured 6 feet two inches in length, and that she was 7 feet 8 inches in overall length, including head. The turtle was found turned on her back (presumably by poachers) at 2 A.M., and so must not have crawled much later than midnight, since her nest had been completed. One hundred of the eggs from this nest were transferred to the Martin-county-operated House of Refuge Historical Museum on Hutchinson's Island opposite Jensen Beach and reburied there. On the morning of August 4, 66 days later, 20 turtles hatched from the nest, and on the next day 5 more were found alive when the site was dug out. The remaining 75 eggs had spoiled. This low percentage of hatch was probably due to the handling of the eggs and perhaps to unnatural conditions of reburial. Despite this, the information gained from the operation is of particular significance since it gives for the first time an indication of the time required for eggs of the Atlantic leatherback to hatch. Of the turtles that hatched, six were retained by the House of Refuge, three were given to the Bay Wood Smoked Fishery at Ft. Pierce, and 16 were presented to the Miami Seaquarium. Pfister reports that all of those kept at the House of Refuge died very quickly, and that the ones given to the Bay Wood Smoked Fishery fed well on kingfish, *Scomberomorus cavalla* (Cuvier), roe, and algae, until they escaped their crawl about the 25th of August, some 21 days after hatching. Of those sent to the Miami Seaquarium, Craig Phillips, Curator, wrote as follows:

> " . . . baby *Dermocheles* lived for some time, the final one dying while I was on vacation from Oct. 1 to Oct. 15, 1957. Several days after their arrival on August 9, all were feeding voluntarily on ground clam and squid. On Aug. 10 I force-fed them their first meal of clam, which they soon learned to take without hesitation. After a couple of weeks they were eating chopped fish as well, and despite their growth, they continued to die one after another.
>
> "I kept them in four ten-gallon glass tanks with two baby loggerheads in each tank with the trunkbacks [leatherbacks] in hopes that the readily-feeding loggerheads would create a psychological atmosphere favorable to the trunkbacks. Whether this did or not I cannot say, but at least they all fed fairly well within a short time.

"Their manner of feeding was rather odd. Compared with the loggerheads, their movements were stiff and mechanical. They seemed to have trouble submerging to the bottom of the tank, so at feeding time (once a day) I lowered the water to about two inches so that they could reach the food without having to submerge. Feeding was accomplished by rapid opening and closings of the jaws accompanied by sidewise jerkings of the head. They seldom appeared to approach the food deliberately, but it appeared as rather a hit-or-miss proposition with them. The jaws were capable of opening to a remarkable extent for a turtle.

"They kept a constant beating with their flippers, never ceasing to bump the glass with their snouts except while feeding or during rare periods of rest. Several developed sore snouts, but I cleared this up with penicillin ointment in time.

"When slightly over a week old, they appeared to begin to lose the granular scales which covered the body, head, and flippers. [see Carr, 1952: 447; Caldwell, Carr, and Hellier, 1956: 280.] These scales gradually rubbed off in patches, and at the time I at first thought that they were developing some kind of fungus skin disease. As the scales rubbed off, the underlying skin bore a faint imprint of the scales and was a lighter, grayer, color than before the moult. Meanwhile, the color pattern became more intensified, the whitish stripes [Caldwell, Carr, and Hellier, 1956: 280] showing even whiter as they grew."

Agent Pearce, who reported the nesting record for June 11 (Table 1), said this turtle laid 129 eggs, about 20 of which were of irregular size. The occurrence of off-sized eggs in Atlantic leatherbacks was reported by Gosse (1851: 306—record repeated by Carr, 1952: 452) and illustrated by Caldwell, Carr, and Hellier (1956: 282). The proportions of "normal-sized" to "abnormal-sized" eggs from this nest are almost identical with those reported for a clutch of eggs for this race of turtle in Trinidad (Caldwell, Carr, and Hellier, 1956: 282) and for the Pacific leatherback, *Dermochelys coriacea schlegelii* (Garman)—see Carr (1952: 460).

Figure 1. *Dermochelys coriacea coriacea* (Linnaeus), young, approximately three to four feet in carapace length, shot in the Indian River, Indian River County, Florida, in the summer of 1954.

Pearce's turtle, the carapace of which was 5 feet 3 inches long and three feet one inch wide, nested early in the evening—about 7 P.M.

The turtle nesting at Juno Beach on July 10 (Table 1) had a carapace length of 6 feet 7 inches and width of 3 feet one inch. Laying early in the evening (about 8 P.M.), it deposited 144 eggs. The eggs from this and the June 11th nesting were removed to the House of Refuge, but all failed to hatch.

Carr (1952: 448) notes that the Atlantic leatherback is frequently reported in Chesapeake and other inshore bays of the northern coast of North America, despite the usual association of the species with an offshore habitat. He suggested that this shoreward movement may in part be influenced by the increasing chill of the water in these northward extralimital parts of the turtle's range. It is therefore of interest to note that in the summer of 1954 a leatherback was shot in the Indian River (a long bay or lagoon protected by an outer string of barrier islands), Indian River County, on the lower Atlantic coast in Florida. In this case, being summer in the sub-tropics, when the water both inshore and offshore would be quite warm, the seeking of warm water temperatures was apparently not an influencing factor for the presence of the turtle inshore. Although no measurements were taken, snapshots furnished Pfister (Figure 1) show that the turtle was small—perhaps no more than four feet in carapace length, and probably nearer three. The The ventral (plastral) coloration of this individual is very similar to that of the hatchling illustrated by Caldwell, Carr, and Hellier (1956: 280), except that the ventral surfaces of the flippers are considerably lighter in the older specimen. The carapace and dorsal surfaces of the flippers, however, are randomly marked with light spots, rather than having the light coloration following only the carapace ridges and trailing edges of the flippers as in the hatchling noted above. Apparently the spots are gradually lost with increase in age and size (Carr, 1952: 447). These appear to be the first published photographs showing the coloration of an Atlantic leatherback of this size.

It is a pleasure to acknowledge the excellent cooperation afforded the sea turtle studies by the Florida State Board of Conservation, and especially by its agents Pfister, Pearce, and Byrd. Craig Phillips, Curator at the Miami Seaquarium, was most generous in allowing me to include his comments on the hatchlings

sent him. I also wish to thank Archie Carr, of the University of Florida, and William W. Anderson, Frederick H. Berry, and Jack W. Gehringer, of the United States Fish and Wildlife Service at Brunswick, Georgia, for their comments regarding the manuscript. Thomas R. Hellier, Jr., now of the University of Texas, spent many hours "turtle watching" with me, and without his help some of these records would not have ben reported.

Literature Cited

ALLEN, E. ROSS, and WILFRED T. NEILL
1957. Another record of the Atlantic Leatherback, *Dermochelys c. coriacea,* nesting on the Florida coast. *Copeia,* 1957 (2): 143-144.

CALDWELL, DAVID K., ARCHIE CARR, and THOMAS R. HELLIER, JR.
1956. A nest of the Atlantic Leatherback turtle, *Dercochelys coriacea coriacea* (Linnaeus), on the Atlantic coast of Florida, with a summary of American nesting records. *Quart. Journ. Fla. Acad. Sci.,* 18 (4): 279-284.

CARR, ARCHIE
1952. *Handbook of Turtles.* Comstock Publishing Associates, a division of Cornell University Press, Ithaca, New York, pp. xv + 542.

GOSSE, P. H.
1851. *A Naturalist's Sojourn in Jamaica.* Longman, London, pp. xxiv + 508.

OBSERVATIONS ON TROPICAL MARINE FISHES FROM THE NORTHEASTERN GULF OF MEXICO [1]

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Recent reports (Caldwell and Briggs, 1957; Briggs and Caldwell, 1957; Briggs, 1958) have revealed the presence of a Florida marine tropical shorefish fauna in the northeastern Gulf of Mexico extending for approximately 60 miles of shoreline from about Panama City to Destin, with the greater concentration of records at Panama City. The extent of this fauna inshore has not been clearly demonstrated—by species or geographical range. The tropical fishes might occur all along the western edge of peninsular Florida in deep water, but there are as yet no published records of occurrence inshore between Panama City and the Keys—despite extensive studies of inshore fishes at Alligator Harbor, some 120 shoreline miles east of Panama City (Joseph and Yerger, 1956); and at Cedar Keys, some 115 shoreline miles further east and south of Alligator Harbor (Reid, 1954; Kilby, 1955; Caldwell, 1954, 1955, 1957; Berry, 1958a, 1958b). Unpublished observations by other workers indicate that some species of tropical shorefish may occur, close inshore, further north along peninsula Florida than the Keys. West of Destin, the extent of the fauna is uncertain—there being unconfirmed and unpublished reports of tropical fishes (species unlisted) as far west as Pensacola, Florida (40 shoreline miles west of Destin), although my own limited collecting inshore there failed to produce any. Boschung, in his 1957 list of Alabama shore fishes (particularly Mobile Bay, 50 shoreline miles west of Pensacola), lists none of the typically tropical fishes recorded from Destin and Panama City.

The tropical fauna at Panama City and Destin is a summer one, and a possible explanation for its occurrence may lie in a combination of factors—pelagic larvae (or at least young that are known to drift in the shelter of floating seaweed) of the tropical species of fish there, and the recently discovered current patterns in the Gulf of Mexico. In this latter regard, Leipper (1954: 121) reports

[1] Contribution number 41 from the U. S. Fish and Wildlife Service Biological Laboratory, Brunswick, Georgia, and a contribution from the Florida State Museum.

summer surface currents in the Gulf, and his illustration shows a sweep of a branch of the Gulf Stream flowing northward through the central Gulf from the Caribbean—where these fishes are always in evidence. This branch is shown as dividing off the Mississippi River Delta with the easterly section bending shoreward in the region including Panama City and Destin. Some young fishes, as inhabitants of floating weed or as pelagic larvae (hatched further south in late winter, spring, or early summer), could be easily swept inshore at this point, and there find suitable habitat until the cold of fall and winter drives them into deeper and warmer water or kills them. As corroborating evidence for such a recruitment of young, only a few adults are found. The great majority of the fauna consists of small individuals probably in their first year. The few adults may move to deep water in fall and winter and return inshore with the onset of warm weather, and while conditions may permit these few to spawn, it appears that the bulk of the summer tropical population may be maintained through annual recruitment from the Caribbean. Why *Acanthurus randalli* Briggs and Caldwell might have become established as a replacement in the northeastern Gulf for the more southern *A. bahianus* Castelnau is not understood. Perhaps future collections will show instead that it does not replace *A. bahianus*, but that both occur there. If the differences between *A. randalli* and *A. bahianus* are the result of ecological influence, it is surprising that the other tropical Western Atlantic species of the genus, *A. chirurgus* (Bloch) and *A. coeruleus* Bloch and Schneider, are not also influenced (Caldwell and Briggs, 1957: 4; Briggs and Caldwell, 1957: 43).

The eastward section of the Gulf Stream branch noted above turns south after bathing the Panama City-Destin shore and flows offshore out of the Gulf through the Florida Straits. In its southward flow it causes some circulation of water back north inshore along the west coast of the Florida peninsula (Leipper, 1954: 121) which may deposit some of the tropical fishes, escaping from the main stream, along the southwestern shore of the Peninsula, and in addition may help populate the more offshore coral and sponge patches shown by Hedgpeth (1954: 206). The absence of tropical species inshore between Panama City and somewhere south of Cedar Key may be due in part to lack of suitable habitat and to too few recruits remaining in the current by the time it influences

that part of the coast. Briggs (1958: 244) opined that the apparent differences between the shorefish faunas of the eastern and western Gulf are due to differences in bottom type. Therefore, the presence of many tropical elements in the eastern Gulf is probably influenced by the combined factors of suitable habitat and regular recruitment by currents from further south.

The occasional record of a tropical species from Texas (Baughman, 1950) may be the result of similar recruitment aided by the portion of the Gulf Stream branch that flows westward after it divides off Louisiana. Less frequent areas of suitable habitat (Briggs, 1958: 244) for the recruits would seem to account for the smaller number of records for tropical fishes in the northwestern Gulf—both as individuals and species.

The following notes on tropical species have been assembled to record one species each from Panama City and Destin for the first time, to indicate that specimens are now available of another species previously recorded only on sight records, to extend the range of a species known only from its type locality at Panama City, and to modify statements regarding three species recorded by Caldwell and Briggs (1957).

Lengths are standard length. UF refers to the University of Florida Collections at Gainesville. BLBG refers to the collections (no catalog numbers) of the United States Fish and Wildlife Service Biological Laboratory at Brunswick, Georgia.

I wish to thank William W. Anderson, Frederick H. Berry, and Jack W. Gehringer, all of the Brunswick Laboratory, for helpful criticisms of this manuscript.

Annotated List

Abudefduf saxatilis (Linnaeus). In reporting this species from Panama City, Caldwell and Briggs (1957: 4) overlooked a paper by Baughman (1950: 252) which questionably included a supposed sight record of *A. saxatilis*, under the name of *A. marginatus* (Bloch), in a list of notes on Texas fishes. I wish to thank Victor G. Springer for bringing Baughman's paper to my attention. The Panama City record is thus the first from the *northeastern* Gulf of Mexico, an area often considered faunistically distinct from the northwestern Gulf west of the Mississippi Delta (see Briggs, 1958: 242).

Chaetodon ocellatus Bloch. This species previously was reported (Caldwell and Briggs, 1957: 3) from Destin, Florida. Specimens have now been taken at the jetties at Panama City by the staff of Florida's Gulfarium in June, 1958. These are: UF 7205, two, 18 and 39 mm.; and BLBG, two, 22 and 25 mm.

Baughman (1950: 252) listed this species from Blind Pass, St. Joseph's Island, Texas. Like the record of *Abudefduf* noted above, this Texas record was overlooked, and the specimens from Destin and Panama City are thus the first from the *northeastern* Gulf of Mexico and have the same zoogeographic significance as those of *Abudefduf*.

Chaetodon striatus Linnaeus. Although reported previously from Panama City (Caldwell and Briggs, 1957: 3), the record was based on sight observations only. Specimens collected by the staff of Florida's Gulfarium in June, 1958, from Destin, corroborate the earlier record of this species in the region. These specimens are: UF 7206, two, 35 and 39 mm.; and BLBG, one, 33 mm.

Eupomacentrus variabilis Castelnau. In an earlier paper listing tropical fishes from Panama City (Caldwell and Briggs, 1957: 4), the name *Pomacentrus xanthurus* Poey was tentatively applied to this damselfish. In a subsequent examination of the material, Loren P. Woods, of the Chicago Natural History Museum, applied the name *E. variabilis*.

Acanthurus randalli Briggs and Caldwell. In preparing the original description for this species (Briggs and Caldwell, 1957), specimens were available only from the type locality at Panama City. There is now an 88-mm. specimen (UF 5674), from off Destin, collected in the fall of 1956 by the staff of Florida's Gulfarium. While the distance involved is only some 60 shoreline miles, this specimen is of interest as it provides for the first time a "range" other than the type locality.

Dermatolepis inermis (Valenciennes). A single 365-mm. specimen, BLBG, was collected in the fall of 1957 off Destin by the staff of Florida's Gulfarium. Briggs (1958: 271) lists the range of this species as Bermuda and southern Florida to Fernando de Noronha, Brazil; and the Destin specimen is therefore apparently the first record from the northern Gulf of Mexico.

Thallasoma bifasciatum (Bloch). A 90-mm. specimen, BLBG, collected in the summer of 1958 by the staff of Florida's Gulfarium,

apparently constitutes a range extension to the Panama City jetties from the Florida Keys. Briggs (1958: 284) listed this species as occurring from Bermuda and the Florida Keys to Colombia and the southwestern Gulf of Mexico.

Literature Cited

BAUGHMAN, J. L.

1950. Random notes on Texas fishes. Part II. *The Texas Jour. Sci.*, 2(2): 242-263.

BERRY, FREDERICK H.

1958a. Additions to the fishes known from the vicinity of Cedar Key, Florida. *Quart. Jour. Florida Acad. Sci.*, 20(4): 232.

1958b. Additions to the fishes of Cedar Key, Florida, and a list of Gulf of Mexico Carangidae. *Quart. Jour. Florida Acad. Sci.*, 21(2): 190.

BOSCHUNG, HERBERT T., JR.

1957. The fishes of Mobile Bay and the Gulf coast of Alabama. Doctoral thesis, University of Alabama, 1957. 626 pp.

BRIGGS, JOHN C.

1958. A list of Florida fishes and their distribution. *Bull. Florida St. Mus., Biol. Sci.*, 2(8): 223-318.

BRIGGS, JOHN C., and DAVID K. CALDWELL

1957. *Acanthurus randalli*, a new surgeon fish from the Gulf of Mexico. *Bull. Florida St. Mus., Biol. Sci.*, 2(4): 43-51.

CALDWELL, DAVID K.

1954. Additions to the known fish fauna in the vicinity of Cedar Key, Florida. *Quart. Jour. Florida Acad. Sci.*, 17(3): 182-184.

1955. Further additions to the known fish fauna in the vicinity of Cedar Key, Florida. *Quart. Jour. Florida Acad. Sci.*, 18(1): 48.

1957. Additional records of marine fishes from the vicinity of Cedar Key, Florida. *Quart. Jour. Florida Acad. Sci.*, 20(2): 126-128.

CALDWELL, DAVID K., and JOHN C. BRIGGS

1957. Range extensions of Western North Atlantic fishes with notes on some soles of the genus *Gymnachirus*. *Bull. Florida St. Mus., Biol. Sci.*, 2(1): 1-11.

HEDGPETH, JOEL W.

1954. Bottom communities of the Gulf of Mexico. *In* Galtsoff, Paul S., Gulf of Mexico. Its origin, waters, and marine life. *U. S. Fish and Wildlife Service, Fish. Bull.*, no. 89, 55: 203-214.

JOSEPH, EDWIN B., and RALPH W. YERGER

1956. The fishes of Alligator Harbor, Florida, with notes on their natural

history. *Florida State Univ. Studies,* no. 22, *Papers from the Oceanogr. Inst.,* no. 2, pp. 111-156.

KILBY, JOHN D.
1955. The fishes of two Gulf coastal marsh areas of Florida. *Tulane Stud. Zool.,* 2(8): 175-247.

LEIPPER, DALE F.
1954. Physical oceanography of the Gulf of Mexico. *In* Galtsoff, Paul S., Gulf of Mexico. Its origin, waters, and marine life. *U. S. Fish and Wildlife Serv., Fish. Bull.,* no. 89, 55: 119-137.

REID, GEORGE K., JR.
1954. An ecological study of the Gulf of Mexico fishes, in the vicinity of Cedar Key, Florida. *Bull. Mar. Sci. of the Gulf and Carib.,* 4(1): 1-94.

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THE ATLANTIC LOGGERHEAD SEA TURTLE, CARETTA CARETTA (L.), IN AMERICA

I. NESTING AND MIGRATION OF THE ATLANTIC LOGGERHEAD TURTLE
David K. Caldwell, Archie Carr, and Larry H. Ogren

II. MULTIPLE AND GROUP NESTING BY THE ATLANTIC LOGGERHEAD TURTLE
David K. Caldwell, Frederick H. Berry, Archie Carr, and Robert A. Ragotzkie

III. THE LOGGERHEAD TURTLES OF CAPE ROMAIN, SOUTH CAROLINA
Abridged and annotated by David K. Caldwell

UNIVERSITY OF FLORIDA
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THE ATLANTIC LOGGERHEAD SEA TURTLE, *CARETTA CARETTA CARETTA* (L.), IN AMERICA

David K. Caldwell, Archie Carr, and others

Coordinators' Preface

When the series of studies now being carried on under National Science Foundation sponsorship (NSF project G-1684 and G-5479, principal investigator Archie Carr) was planned it was proposed that the Atlantic green turtle, *Chelonia mydas mydas* (Linnaeus), be made the central subject of the research. The herbivorousness of green turtles was visualized as imposing on them a distinctive way of life, involving long periodic journeys between feeding and breeding grounds. This, in turn, was seen as a unique attribute, setting *Chelonia* off from other sea turtles—making it easy to study because it gathers to breed in rookeries, and especially interesting because the journeys to and from the rookeries posed special problems of orientation and suggested that *Chelonia* must have an extraordinary capacity to navigate. While all this still seems true, it is now clear that differences among sea turtles with respect to reproductive travel are less than was supposed.

Data from a tagging program at Tortuguero, Costa Rica, have been strengthening the credibility of fishermen's tales of navigatory feats by green turtles. These stories constituted the original assumption to be tested by the Tortuguero studies, and while final proof of their authenticity will be difficult to get, there remains no real doubt of their essential truth. While the case for the navigatory prowess of *Chelonia* has been growing, information from various other sources has suggested that *all* sea turtles migrate.

The following suite of papers supports our belief that the life cycle of the carnivorous Atlantic loggerhead, *Caretta caretta caretta* (Linnaeus), may in most ways be much more similar to that of the green turtle than we imagined. Like the green turtle, the loggerhead travels far, it travels in groups, it emerges more than once to complete a season's laying, it tends to return to the same place for successive layings and is able to locate these sites with some precision, and its breeding range includes places where aggregated nesting occurs as well as sites of separate emergence by lone individuals. Details of nesting and development of the young and their early behavior also are surprisingly similar for all the sea turtles.

To most people, including most zoologists, the loggerhead is an animal to be seen on the sea beach as a nesting female or an emerging hatchling, or at shipside or dockside as a big head stuck up out of the water to breathe. We really know almost nothing about what goes on between these few points of our contact with the animal. Though the information that can be added is fragmentary, it fits in with the fishermen's stories and our growing belief in the essential consonance of the life cycles of all the sea turtles.

The three papers on loggerheads included in this series were prepared independently. They are closely related, even overlapping in some aspects, and it was felt that workers in herpetology and marine ecology would find it convenient to have them available under one cover. We, and the various other authors, are indebted to our respective organizations for permitting, and to the editorial staff of the Bulletin for countenancing this unorthodox style of presentation.

David K. Caldwell, United States
Fish and Wildlife Service,
and
Archie Carr, University of Florida,
Coordinators.
March, 1959

I. NESTING AND MIGRATION OF THE ATLANTIC LOGGERHEAD TURTLE [1]

David K. Caldwell,[2] Archie Carr,[3] and Larry H. Ogren[4]

Synopsis: Tagging evidence shows that female Atlantic loggerhead sea turtles may travel as much as 1000 shoreline miles away from the nesting beach in 10 months.

The nesting procedure of the Atlantic loggerhead is described and illustrated. The loggerhead sometimes nests singly, but more often in aggregations on restricted stretches of beach. Loggerheads mate in the water just off the nesting beach, though whether before or after nesting, or both, is still unknown. No correlation exists between the size of the turtle and the time of laying or the number of eggs laid.

The principal nesting range of the subspecies is the mainland coast of North America from about Cape Lookout, North Carolina, to Mexico; emergences have been recorded occasionally on certain northern Caribbean islands and as far south as Costa Rica. The Atlantic and Pacific subspecies of the loggerhead cannot be separated by their marginal laminae.

Despite the large size of the Atlantic loggerhead turtle, *Caretta caretta caretta* (Linnaeus), and its common occurrence along heavily populated shores, its movements and certain details of its nesting habits are still poorly known. This is an account of recent observations on the species' nesting and of results of tagging operations on the coasts of Georgia and Florida.

Migration

Long Range Travel

It has long been suspected that the stray loggerheads found occasionally in European waters were individuals from American waters, where the nearest upstream nesting grounds lie (in relation to the Gulf Stream). Although it may never be possible to prove the Amer-

[1] Field work supported in part by National Science Foundation Grants G-1684 and G-5479 (University of Florida, Principal Investigator Archie Carr). Contribution number 42 from the United States Fish and Wildlife Service Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia.

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ican origin of the European loggerheads, and while it may eventually be shown that they derive from downstream rookeries, on the Mediterranean coasts for example, we now at least have a tag return which proves an impressive distance traveled between known points during a known period of time.

The turtle recovered was a female with a carapace length (measured as described by Carr and Caldwell, 1956: 4) of 35 inches, tagged by Caldwell and Thomas R. Hellier, Jr. while nesting at Hutchinson's Island, opposite Jensen Beach, Martin County, Florida, on 27 May 1957. It was recaptured by a shrimp trawler off the mouth of the Mississippi river, probably near Pass-a-Loutre, about 24 or 25 March 1958. It was thus at liberty for about 302 days and was retaken about 1000 shoreline miles from the place of tagging. To reach the point of recapture by the shortest route without crossing the open Gulf, this turtle had to travel southward around the tip of Florida and then northward and westward into the north-central Gulf of Mexico. The length of time between tagging and recapture suggests the animal may have taken a more circuitous inshore route. Although the trip might seem to imply continuous travel against the Gulf Stream, an examination of major seasonal current systems in the Gulf of Mexico (as given by Leipper, 1954: 121-122) shows that the turtle might actually have been helped by currents. Caldwell, Berry, Carr, and Ragotzkie (1959 herein) show that loggerheads nest more than once a season. Although by no means proved, it also seems likely that they remain in the general vicinity of the rookery area throughout the nesting season, or until late summer. If this turtle left the Jensen Beach area in late August, it could have passed around the southern tip of Florida free of opposition by the Gulf Stream simply by staying close inshore until it reached Florida Bay. From the southeastern Gulf of Mexico the currents flowing generally northward and westward along the eastern Gulf coast in the late winter and early spring could have helped it reach the Mississippi by March. This is one of the longest journeys ever proved for any reptile, being rivalled only by trips made by female green turtles tagged in Costa Rica (Carr and Ogren, Ms.).

The only other tagged loggerhead recovered an appreciable distance from where it was marked made a much shorter journey in much less time. Caldwell, Carr, and Hellier (1956b) reported an individual tagged when nesting at Fort Pierce, (Hutchinson's Island, Florida), and recaptured 3 weeks later by a shrimp trawler off Daytona Beach, Florida, some 130 shoreline miles northward. The re-

covery indicates that mature loggerheads may travel considerable distances in a fairly short period of time. This turtle, like the other, could have been helped by ocean currents, in this case the northward-flowing Gulf Stream.

Movements of the Hatchling

One of the major problems in the study of sea-turtle life histories is the question of where the post-hatchlings spend the first months after they leave the nest. It has been pointed out (Deraniyagala, 1939; Carr, 1952) that small specimens of the Atlantic ridley sea turtle, *Lepidochelys kempi* (Garman), occasionally reach points far distant (England, for example) from their probable natal beaches. Such occurrences suggest a passive migration in the form of a post-hatchling drifting in the major ocean currents, the Gulf Stream in particular. The ridley is the only species in which this conjecture has been supported by concrete evidence, and even this is meager.

We know of no previous records of sea turtle hatchlings taken away from a nesting beach or at sea. Two recent captures are thus of interest. William W. Anderson took a young loggerhead in a dipnet at the surface in 200-fathom water at 25° 10′ N., 80° 02′ W., about 15 miles southeast of Key Largo, Florida, 26 July 1957. This animal, now in the collection of the Bureau of Commercial Fisheries Biological Laboratory at Brunswick, Georgia, still has its egg tooth and umbilical scar and measures 64 mm. in carapace length. Two other hatchlings, one badly macerated, the other in fair condition, were taken from the belly of a 7-foot female white-tipped sharp (*Carcharhinus longimanus*) caught at 30° 50′ N., 78° 45′ W., 135 miles due east of Cumberland Island, Georgia, 22 August 1957. These specimens, now in the University of Florida Collections, show juvenile characters and measure 47.5 mm. in carapace length. They were sent us by Dr. Richard Backus of the Woods Hole Oceanographic Institution, who has been consistently generous with sea turtle data gathered incidental to his oceanographic studies.

Comparison with captive loggerheads of known age (cf. Caldwell, Carr, and Hellier, 1956b: 297) suggests the first specimen was about 11 weeks old, the second two about 12 to 13 days old when eaten. Whether these turtles were lost waifs drifting to oblivion in the open sea, or whether they occur in these localities regularly after leaving the nesting beaches is still uncertain. If they occur in these waters regularly, it is strange that the biologists who have spent hundreds of hours observing and dipnetting there have reported no others.

Mating and the Nesting Process

Colonial Nesting

Although the loggerhead nests on the beaches of all the coastal South Atlantic and Gulf states roughly from Cape Lookout, North Carolina, to Texas, it apparently concentrates its nesting activity in restricted areas which may conveniently be termed "rookeries." Similar rookeries are known for other species of sea turtles, particularly the green turtle. We have found three such nesting concentrations of loggerheads on the Atlantic coast of the United States; one is Hutchinson's Island, Florida; another is Jekyll Island and the adjacent Little Cumberland Island near Brunswick, Georgia; the third is Cape Romain, South Carolina, fortunately located within a United States Fish and Wildlife Service wildlife refuge. Aerial reconnaissance of the coast of Florida north of Matanzas Inlet, of the entire coast of Georgia and of most of that of South Carolina, has shown the apparent concentration of nesting activity on Jekyll and Little Cumberland Islands and at Cape Romain to be real. While a few nests were observed scattered along the entire stretch of coast, each flight showed the places mentioned to be far more heavily used than any other area. Surveys of the south Florida coast indicate that Hutchinson's Island is similarly important as a rookery.

In addition to the concentration of tracks seen from blimps on Jekyll and Little Cumberland Islands, evidence that these islands near Brunswick are used as a rookery has been supplied by William W. Anderson. While conducting shrimp studies for the Fish and Wildlife Service with the Brunswick shrimp fishery off the Georgia islands, particularly from 1930 to 1938, he found loggerheads quite rare in the area each year during the fall, winter, and early spring. In late spring as the summer nesting season approached, the turtles appeared in large numbers in these particular waters, and were seen nowhere else in abundance, neither off neighboring islands nor in the sounds and passes. The turtles off Brunswick were at times plentiful enough to be a nuisance to the shrimp fishermen whose trawls they damaged. As shrimping continued after the turtle nesting season, it provided a good sampling opportunity, which indicated a real influx of mature-sized loggerheads from outside the rookery area during the nesting season. Brunswick shrimp fishermen working today say that although the total loggerhead population has been reduced, this same seasonality in abundance occurs.

Mating

In both the Atlantic and Pacific green turtles mating occurs mainly off the nesting beach (Harrisson, 1954; Carr and Giovannoli, 1957: 30.). William W. Anderson's observations suggest that similar behavior is characteristic of loggerheads. He had excellent opportunities between 1930 and 1938 to observe the turtles clearly from his slow-moving trawler, and states that he often saw loggerheads mating in the water just off the Georgia beaches, particularly near the passes between the sea islands where the beaches are located. Not being aware at the time of the scarcity of such data, Anderson kept no records of dates, but he clearly recalls that this mating behavior took place each year he worked in the area, and always during the nesting season of the loggerhead. His observations agree with those of others that mating loggerheads tend to ignore a nearby boat. He never saw mating turtles in threes—a female with two attending males—as has been reported for the green turtle by Carr (1956) and by Carr and Giovannoli (1957: 31); although elsewhere we have been told of observations of such trios of loggerheads (see also Caldwell, 1959, herein).

Anderson noted that the influx of turtles to the waters off the nesting beaches began as much as a month before actual nesting. This fact may bear on the problem of whether mating occurs just before laying or afterwards, a detail not yet determined for any species of American sea turtle (Carr and Giovannoli, 1957: 31; Carr and Ogren, Ms).

Nest Building and Oviposition

Although the nesting of the Atlantic loggerhead frequently has been described in popular articles, the only accounts in zoological literature that recount the process in detail are the composite descriptions of Mast (1911) and Carr (1952: 390). After observing nesting loggerheads for several seasons we find that these accounts require modification. Accordingly we present the following description of the nesting of the Atlantic loggerhead and the accompanying series of photographs showing some of the more important details. Both the notes and pictures are composites, because it is difficult to find turtles just emerging from the sea and to follow and photograph the entire procedure of a single individual. However, the behavior was so similar in all localities and at all times of the nesting season that the account given here is believed to be representative of the Atlantic loggerhead on the coasts of Florida and Georgia.

Figure 1.—Nesting Atlantic loggerhead, showing large excavation made preliminary to actual digging of nest (see text).
Figure 2.—Flipper inserted into growing nest cavity.
Figure 3.—Flipper lifting sand out of nest cavity.
Figure 4.—Left flipper digging, right flipper flat on sand.
Figure 5.—Head down and neck arched prior to laying. Note open eye and tears.
Figure 6.—Hind flippers raised before group of eggs is extruded.
Figure 7.—Hind flippers lie flat on surface of sand during intervals between extrusions of eggs.
Figure 8.—Head raised between extrusions of eggs. Note tears and open eye.

On first leaving the water, and even until she has started to dig, the turtle is easily disturbed. She reacts strongly to a light thrown directly upon her. Contrary to Carr's account (1952: 390), after the site for the evening's activity is selected all turtles observed dug a preliminary excavation of varying extent. The female uses all four flippers in this process until she has lowered herself several inches below the surface of the sand (Figure 1). Digging of the actual nest follows almost immediately, for which only the hind flippers working alternately are used. With its outer edge downward, one flipper is inserted into the sand or into the growing hole (Figure 2). It is then cupped, and the outer edge is rotated inwardly. A small amount of sand is now scooped up (Figure 3), lifted to the top of the hole, and deftly laid to one side. Meanwhile the opposing flipper remains flat, "palm" down on the sand near the edge of the hole (Figure 4). The turtle now shifts her body so this other flipper comes into position over the hole. Just before she inserts it into the hole to dig, she flicks it out laterally and upward to brush the loose sand, deposited when this flipper last excavated, away from the edge of the hole. This technique differs only in minor points from that described for the green turtle by Carr and Giovannoli (1957: 25).

The digging process is then repeated as the turtle shifts to bring the first flipper into play again. Almost as soon as the nest is finished the flippers are laid straight back or pointed slightly outward, "palms" down (Figure 7), and the cloacal "ovipositer" is inserted. During the digging process the head has been held flat on the sand and the eyes kept open, although blinking occasionally. The eyes secrete copiously (Figures 5 and 8) during the digging and laying. Just before each group of eggs falls (in groups of one, two, or three) the neck is arched with the head still down (Figure 5), and the hind flippers are raised slightly (Figure 6). As each group of eggs falls, the neck is lowered to the position held during digging and the flippers come down and lie flat again between extrusions (Figure 7). During this interval, the head may be raised slightly (Figure 8) and the turtle may snort or sigh by expelling air from her nostrils or mouth.

Carr and Giovannoli (1957: 25) stated that the loggerhead will press its vertically oriented back flippers against the upper part of the wall of the nest cavity "as if to keep sand from falling in," and Carr (1952: 11) illustrates the maneuver in *Lepidochelys*. Despite numerous attempts, we never succeeded in bringing about this behavior in a laying Atlantic loggerhead. Several times we dug part of the wall of the nest away to reveal the eggs for photography, and never did the

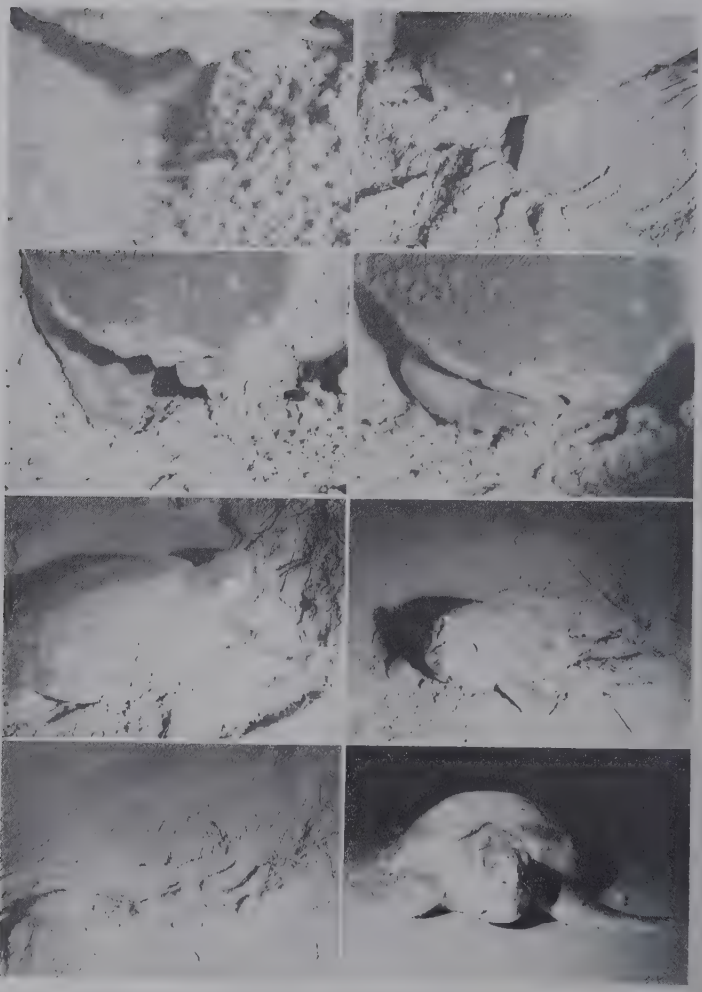

Figure 9.—Nearly cylindrical nest cavity almost filled with eggs.
Figure 10.—Rear flipper dragging sand to fill nest and cover eggs.
Figure 11.—Hind flippers packing sand in filled nest.
Figure 12.—Hind flippers packing sand in filled nest.
Figure 13.—All flippers sweeping sand to conceal the site.
Figure 14.—Turtle about to leave the nest. Note lifted head, open eye, and prominent hyoid apparatus.
Figure 15.—Nest site after departure of turtle. Trail leads off to left.
Figure 16.—Turtle crawling to the surf after nesting. Note position of head.

turtle attempt to shore up the crumbling nest. Once when we moved the posterior end of the turtle away from the nest opening she continued to lay on the surface of the sand beside it. When replaced over the hole, she continued to lay as if nothing had happened.

When the nest is filled with eggs (Figure 9), covering begins almost immediately. Sand is drawn in by the hind flippers, usually working alternately, sometimes together. The outer edge of the flipper is used, the limb reaching well forward and out from the body to drag sand back to the hole (Figure 10). As filling proceeds, the front flippers join in sweeping sand backward to replenish that pushed into the nest cavity by the hind legs and, like the hind flippers, the front ones are used either alternately or together. When the hole is full of loose sand, the hind flippers press it down firmly (Figures 11 and 12). During the filling and packing process the head and fore part of the body are sometimes raised as if to shift weight to the hind flippers and help them exert more force. Perhaps this shifting and raising of the body to increase pressure at the hind flippers accounts for the impression that the site is "pounded." Although it was expressly watched for, no turtle was seen to pack or pound the nest with her plastron, as reported by Carr (1952: 391). As the filling reaches completion, the front flippers aided somewhat by the hind ones begin to fling sand backward. This increased exertion pivots the turtle on the pedestal of sand her digging leaves under her plastron.

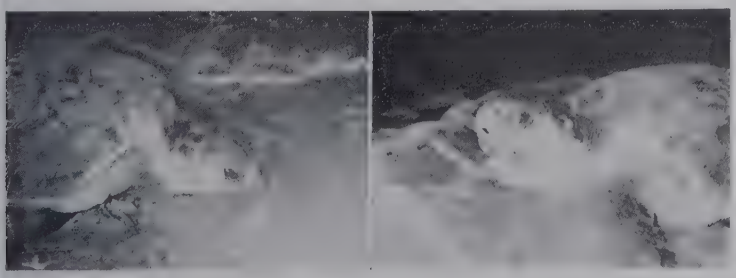

Figure 17.—Arrival at water, snout lowered into surf.
Figure 18.—Head raised before turtle proceeds through surf.

After completing the nest the turtle rests for a short period, and she also rests between the several subsequent outbursts of sand-flinging before moving away from the site. The flinging of sand—presumably aimed at concealing the site, and certainly effective—often enlarges the preliminary excavation (Figure 13). Just as the turtle moves

away from the site she raises her head high with the eyes still open, as they have been throughout the nesting process (Figure 14), and the hyoid apparatus becomes quite prominent as it moves in and out. When she leaves the nest, the site (Figure 15) is so camouflaged that the eggs are hard to find without the aid of a probing rod.

The return trip to the surf is usually made quickly and purposefully. Although the head is slightly raised while the turtle drags herself along (Figure 16), on reaching the water she drops her head into it (Figure 17). After a moment she raises it again (Figure 18) before moving rapidly out of sight into the sea.

Agent Robert Kilby of the Georgia Game and Fish Commission has told us of turtles completing the digging activity, laying a few eggs, beginning to cover these, and then laying the rest of the complement before finally covering the nest.

One collaborator let a turtle complete her nest, and when he turned her to be tagged she layed another mature egg. We allowed one turtle to finish her nest and then killed her to examine her for internal eggs. Though she had laid 90 eggs in a normal fashion and covered her nest, she still retained two mature eggs in the lower oviduct.

While the size of each egg in a clutch remains fairly constant, unlike those of the leatherback, *Dermochelys coriacea coriacea* (Linnaeus), (see Caldwell, Carr and Hellier, 1956a: 282; Caldwell, 1959; Carr and Ogren, in press) we twice found a single tiny egg in a normal clutch at the Jekyll Island rookery. These small eggs, somewhat oblong and measuring about 20 mm. in their greatest dimension, were fully shelled but contained no yolk and only a small amount of albumen. It was not ascertained when they were deposited.

Time of Emergence

Nesting loggerheads usually come out of the sea shortly after dark, and most of their nesting activities take place during the first 4 or 5 hours after dusk (see Caldwell, 1959, herein). As no case of a loggerhead nesting after daylight has been reported in the literature, the following observations are of interest.

On 13 July 1958 Caldwell, in company with Frederick H. Berry and Robert A. Ragotzkie, made a low-altitude aerial survey of the sea beaches from Cape Romain, South Carolina, to Brunswick, Georgia. At 0905 hours they observed a large loggerhead just returning to the water after apparently having nested on a beach just north of the inlet to Charleston Harbor, S. C. Official sunrise was 0500 hours and,

as the day was clear, it was full daylight by 0545. The tide had just turned to flood and, as the tracks leading out of the water extended nearly to the water's edge, the turtle could not have been on the beach more than the normal hour or so. From the air it appeared that this turtle had started and completed a normal nesting during full daylight.

During mid-July 1954 Agent Robert S. Pfister of the Florida State Board of Conservation made a similar observation on Hutchinson's Island about 1 mile south of the Fort Pierce Inlet where he had noted little preivous nesting. A rather small turtle appeared on the beach before sunrise when the dawn was just light enough so that "one would not need lights to drive a car on the highway." The turtle made a leisurely but direct trip to a spot above the high tide mark, dug its nest, laid, covered the eggs, and returned to the water. By then the sun had been above the horizon for a full hour.

A third instance, by coincidence also on 13 July 1958, was reported by Agent Kilby, who saw a turtle on Jekyll Island covering her eggs well after daylight. He believed that she must have left the water at about 0530 to 0600 hours, well after daylight. Kilby found another loggerhead after daylight on the south end of Jekyll Island which he thinks was lost on the broad sand flat, for her back trail was unusually long and meandering.

Agents Pfister and Kilby guard two of the three greatest loggerhead nesting grounds on the entire Atlantic coast of North America. They patrol the beaches in their charge with motor vehicles nearly every night throughout the turtle nesting season, from just after dark to past dawn. They undoubtedly see most of the turtles that emerge on their beaches, possibly more than are seen by any other men alive.

Size of Nesting Females

Carapace lengths to the nearest one-fourth inch were recorded for 110 turtles nesting on Jekyll Island from 29 May through 31 July 1958. The mean length was 37¾ inches, with a range of 31¼ to 45¼ inches. An analysis showed no correlation between the size of the turtles (either mean or range) and the dates they nested.

Size of Turtle in Relation to Number of Eggs Laid

The number of eggs in 25 clutches was compared with the size of the turtles laying them. Analysis of these variables showed no correlation.

Nesting Range

Each year since Carr's first visit to Tortuguero, Costa Rica, in 1953 the local turtle-turners there have reported the emergence of a loggerhead or two among the green turtles, Atlantic hawksbills (*Eretomochelys imbricata imbricata* (Linnaeus)), and Atlantic leatherbacks (*Dermochelys coriacea coriacea* (Linnaeus)). Though hundreds of turtles were examined there during the tagging program (Carr and Giovannoli, 1957; Carr and Ogren, in press; Carr and Ogren Ms.) no loggerhead was found until the summer of 1957, when early in the evening of 29 July a small (carapace length 34 inches) female came out on the beach and was turned by Durham Rankin, a creole in the employ of the project (Figure 19). The southernmost previous recorded emergence for the loggerhead was from the north coast of Cuba (Caldwell, Carr, and Hellier, 1956b: 296), though Lewis (1940: 62) noted that the species is reported to nest on the Cayman Islands.

Figure 19.—Female loggerhead photographed on the beach at Tortuguero, Costa Rica; the first emergence recorded for the species in American waters south of Cuba.

The case presents an extreme example of the tendency, observable in other species of marine turtles and mentioned earlier in this paper as characteristic of loggerheads of the Atlantic coast, to nest either in aggregations or as isolated individuals. Breeding aggregations of animals usually develop integrating bonds that place the

aberrant individual with an urge toward solitary breeding at a selective disadvantage. The chances for consummation of any reproductive venture apart from the group effort, especially when a long migration to the nesting grounds is involved, would appear slight. With the sea turtles we can at present only point out the phenomenon and hope that with better understanding of the organization of the breeding group an explanation will eventually emerge.

Variation in Marginal Laminae

One character used to distinguish between the Atlantic and Pacific subspecies of the loggerhead has been the number of marginal laminae; the Atlantic form is supposed usually to have 12 on each side and the Pacific race 13 (see, for example, Carr, 1952: 382). Counts of the marginal laminae in two small groups of hatchlings, each group from a single clutch of eggs and both from Jekyll Island, show this character to be invalid. In one group 8 specimens had a 13-13 count, 4 a 12-12. The other group had 5 with a 13-13 count, 6 with 12-12, and one with 13 on the left and 12 on the right.

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We are grateful for the cooperation afforded the project in Georgia by the United States Navy (Naval Air Station, Glynco) which granted permission to make reconnaissance flights in their airships. David Gould, Director of Coastal Fisheries for the Georgia Game and Fish Commission, kindly allowed Caldwell to participate in patrol flights by the Commission airplane. The pilot, Clifford G. King, was most gracious in facilitating observations during the flights.

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Literature Cited

Caldwell, David K.

1959. On the status of the Atlantic leatherback turtle, *Dermochelys coriacea coriacea*, as a visitant to Florida nesting beaches, with natural history notes. Quart. Jour. Florida Acad. Sci., vol. 21, no. 3, pp. 285-291, 1 fig.

Caldwell, David K., Archie Carr, and Thomas R. Hellier, Jr.

1956a. A nest of the Atlantic leatherback turtle, *Dermochelys coriacea coriacea* (Linnaeus), on the Atlantic coast of Florida, with a summary of American nesting records. Quart. Jour. Florida Acad. Sci., vol. 18, no. 4, pp. 279-284, 3 figs.

1956b. Natural history notes on the Atlantic loggerhead turtle, *Caretta caretta caretta*. Quart. Jour. Florida Acad. Sci., vol. 18, no. 4, pp. 292-302, 2 figs.

Carr, Archie

1952. Handbook of Turtles. Ithaca, N. Y.: Comstock Publishing Associates, xv + 542 pp., 37 figs., 82 pls., 23 maps.

1956. The Windward Road. New York: Alfred A. Knopf, Inc., xvi + 258 + viii pp., illus.

Carr, Archie, and David K. Caldwell

1956. The ecology and migrations of sea turtles, 1. Results of field work in Florida, 1955. Amer. Mus. Novitates, no. 1793, 23 pp., 4 figs.

Carr, Archie, and Leonard Giovannoli

1957. The ecology and migrations of sea turtles, 2. Results of field work in Costa Rica, 1955. Amer. Mus. Novitates, no. 1835, 32 pp., 13 figs.

Carr, Archie, and Larry H. Ogren

In Press. The ecology and migrations of sea turtles, 3. *Dermochelys* in Costa Rica. Amer. Mus. Novitates, in press.

Manuscript. The ecology and migrations of sea turtles, 4. The green turtle in the Caribbean Sea.

Deraniyagala, P. E. P.

1939. The Mexican loggerhead in Europe. Nature, vol. 144, p. 156.

Harrisson, Tom

1954. The edible turtle (*Chelonia mydas*) in Borneo. 2. Copulation. Sarawak Mus. Jour., new ser., vol. 6, no. 4, pp. 126-128, pl. 20-21.

Leipper, Dale F.

1954. Physical oceanography of the Gulf of Mexico. *In* Galtsoff, Paul S., coordinator. Gulf of Mexico. Its origin, waters, and marine life. U. S. Fish and Wildlife Serv., Fish. Bull., no. 89, pp. 119-137, figs. 34-43.

Lewis, C. Bernard

1940. The Cayman Islands and marine turtle. Bull. Institute of Jamaica, sci. ser., no. 2 (appendix), pp. 56-65.

Mast, S. O.

1911. Behavior of the loggerhead turtle in depositing its eggs. Pap. Tortugas Lab., Carnegie Inst. Washington, vol. 3, pp. 63-67.

II. MULTIPLE AND GROUP NESTING BY THE ATLANTIC LOGGERHEAD TURTLE [5]

David K. Caldwell, Frederick H. Berry,[6] Archie Carr, and Robert A. Ragotzkie[7]

Synopsis: Tagging results and studies of unlaid eggs in dissected females demonstrate that individuals of the Atlantic loggerhead sea turtle nest several times on the same stretch of beach in a summer, but it is not yet known whether each individual lays every year. Individual turtles can locate these places with some precision. Tagging results show groups of turtles nest together several times, and it is believed they stay together during the periods between the nesting emergences.

Although fishermen, turtle poachers, and conservation officers commonly believe that the Atlantic loggerhead sea turtle, *Caretta caretta caretta* (Linnaeus), lays more than once during a season and that groups of turtles remain together during the season to nest together, no detailed observations on these points appear to have been made by biologists. Recent evidence of tagging studies proves multiple emergence and suggests group adherence of individuals. Further evidence that the eggs of a season are laid in two or more batches has been the finding of unlaid eggs in discrete size groups in female turtles dissected during the nesting season. Counts and measurements of such eggs are included in the present paper.

Group Nesting Emergence

In examining their tagging data on the green turtle, *Chelonia mydas mydas* (Linnaeus), for possible evidence of group travel, Carr and Giovannoli (1957: 9) found cases in which individuals that emerged together tended to return to renest together later the same season. We have clumped tag returns that suggest similar group movements in nesting *Caretta*.

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Our first evidence for grouped emergence resulted from limited tagging studies conducted in 1957 at Hutchinson's Island near Fort Pierce, Florida. While not so impressive as the results obtained at Jekyll Island near Brunswick, Georgia, in 1958, to be described below, they nevertheless suggest that group movements may be the rule in loggerheads.

On 27 May 1957 seven nesting loggerheads were tagged on Hutchinson's Island with monel cow-ear tags (Carr and Caldwell, 1956:3) fixed to the front flipper, including one numbered 78. On 28 May 1957, 11 turtles were tagged, including one numbered 23. Number 23 was released within 2 miles of the release point for number 78.

At 0115 hours on 30 June 1957, 34 days after the first tagging date, Agent Robert S. Pfister of the Florida State Board of Conservation found number 23 nesting "7 miles south of the Ft. Pierce Inlet," at approximately the same place where she had been tagged. At 0120 hours only a short distance away, a few hundred yards at most, he found number 78 nesting. In spite of the small size of the sample, the fact that this double return involved two out of a group of only 18 turtles tagged makes it highly improbable that the dual recovery was due to chance. This double return and a long-range recovery in the northern Gulf of Mexico from the 27 May tagging (Caldwell, Carr, and Ogren, 1959, herein) are the only reports to date from 72 turtles tagged on Hutchinson's Island during the 1957 season. This lends significance to the dual recovery and enhances its value as evidence of concurrent movements.

TABLE 1

Numbers of turtles tagged at Jekyll Island, Georgia, in 1958 with monel cow-ear tags, as described by Carr and Caldwell (1956).

early June (date uncertain)	5	9–11 July	4	22 July	1
6 June	6	11 July	5	23 July	1
10 June	4	15 July	6	24 July	2
13 June	7	16 July	7	25 July	3
9 July	4	17 July	6	29 July	1
10 July	1	18 July	6	31 July	3
				Total	72

The results of the 1958 tagging studies on Jekyll Island clearly show this phenomenon of group nesting emergence by loggerheads (table 2). Eight turtles, numbers 125, G43, G47, G103, G105, G107,

G108, and G111, show such close agreement in their dates of first and later emergences that they may be considered as one group. Though our records are indefinite on the point, it is presumed that all laid on the night of tagging or very shortly thereafter. This presumption is based on findings (presented below) that show a turtle emerging and failing to nest one night will return the same or suc-

TABLE 2

RETURNS OF LOGGERHEAD SEA TURTLES TAGGED AT JEKYLL ISLAND, GEORGIA, IN 1958. (ld) DENOTES TURTLE LAID; (dnl) DENOTES TURTLE DID NOT LAY, (nd) DENOTES NO DATA ON NESTING ACTIVITY.

Tag Number[8]	Date Tagged	First Return	Second Return	Third Return
110	June 6 (ld)	July 10 (nd)		
111	June 10 (dnl)	June 16 (ld)	July 5 [9]	
114	June 10 (ld)	July 23 (ld)	July 29 (dnl)	
117	June (?) (nd)	July 18 (nd)		
118	June 13 (dnl)	June 28 (ld)		
120	June (?) (nd)	July 11 (nd)		
121	June (?) (nd)	July 10 (nd)		
123	June 13 (dnl)	July 29 (ld)		
125	June 13 (dnl)	July 16 (ld)	August 1 (ld)	
136	early June (nd)	June 28 (ld)	July 11 (ld)	
144	June (?) (nd)	July 26 (ld)		
147 / G35 [10]	July 11 (nd)	July 14 (dnl)	July 26 (dnl)	
G30	July 10 (dnl)	July 11 (ld)		
G33	July 11 (dnl)	July 23 (ld)		
G37	July 11 (dnl)	July 15 (nd)		
G43	July 15 (dnl)	July 28 (dnl)	July 29 (dnl)	July 30 (ld)
G47	July 16 (ld)	July 31 (ld)		
G49	July 16 (dnl)	July 17 (ld)		
G102	July 16 (dnl)	July 17 (dnl)	July 18 (nd)	
G103	July 17 (ld)	July 30 (ld)		
G105	July 17 (ld)	July 30 (ld)		
G107	July 17 (ld)	July 31 (ld)		
G108	July 17 (ld)	July 30 (ld)		
G111	July 18 (ld)	July 31 (dnl)	August 1 (ld)	
G115	July 22 (dnl)	July 23 (ld)		
G119	July 25 (ld)	August 7 (ld)		

[8] Tags bearing no letter prefix are marked for return to the University of Florida; those bearing a "G" prefix are marked for return to the Georgia Game and Fish Commission.

[9] Turtle found dead on beach. Oviduct contained shelled eggs.

[10] Turtle re-tagged when original tag pulled out during first recapture.

cessive nights until she nests successfully. Thus these turtles returned together as a group to lay again after approximately 2 weeks.

As turtle 125 presumably laid in mid-June, her record suggests that the group nested at least four times that summer, in mid-June, in late June, in mid-July when most were tagged, and in early August. The probability that the grouping shown by this series occurred by chance alone, especially with so few turtles tagged, is so slight that coincidence need not be considered. Possibly another aggregation on Jekyll is the group made up of numbers 110, 120, 121, 147-G35, and G30, but the data for this and possible other groupings are not conclusive.

Aggregate nesting is also suggested by observations William W. Anderson, United States Fish and Wildlife Service, made during a shrimp study for the Service in Georgia from 1930 to 1938. The investigation involved considerable field work and afforded him the opportunity to observe turtles from a small slow-moving boat. Anderson noticed that during the nesting season turtles were not present at all times in great numbers, but rather that they seemed to arrive in the area in groups. Correlated was the general observation that nesting turtles likewise tended to arrive together on the beach.

Later studies conducted at Jekyll Island by Caldwell and Berry showed a similar phenomenon of groups of turtles on the beach at one time, then periods with only an occasional individual present before another group appeared. Thus, while there was a general congregating of turtles in the area during and just before the nesting season, it appears likely that the turtles did not remain in the immediate vicinity between nesting times, but perhaps moved elsewhere to await their time for returning to renest.

Anderson further noted that at no time during the season were turtles abundant in Georgia waters other than those immediately surrounding the rookeries at Jekyll and Little Cumberland Islands. It seems unlikely that the turtles return to their wintering grounds between nestings and regroup before returning for the next nesting venture. There remains for the loggerhead, as for the green turtle (Carr and Giovannoli, 1957; Carr and Ogren, Ms.), the stubborn problem of where they go in the interim. They may go offshore, but observations do not support this.

Multiple Nesting as Shown by Tagging Results

We referred earlier to a return to the Hutchinson's Island beach by two turtles that had nested there about a month before. In the

Atlantic green turtle the interval between the nesting ventures of a season is 12 to 14 days (Carr and Giovannoli, 1957; Carr and Ogren, Ms.). A similar interval was suggested for the loggerhead by Lewis (1940: 62), which our recoveries at Jekyll Island corroborate. Presumably the recovery of the two turtles at Hutchinson's Island after a month's absence must have been preceded by an unrecorded return 2 weeks earlier.

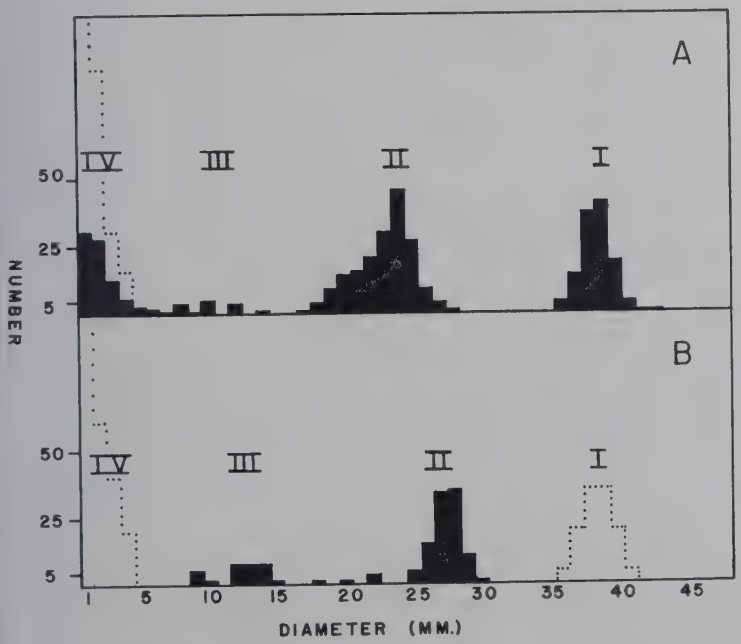

Figure 20.—Diameter-frequencies of freshly laid and ovarian eggs of the Atlantic loggerhead turtle at Jekyll Island, Georgia, in 1957. Solid areas indicate eggs actually measured. Dotted lines indicate estimated numbers of eggs within the indicated ranges of diameters.

From the first week of June through the last week of July 1958, 72 loggerheads were tagged at the Jekyll Island rookery (Table 1). Of these, 26 were recaptured one or more times (Table 2). In addition to these definite records, tourists reported seeing about 10 more tagged turtles on the beach. As no data accompanied these reports they are of no value in piecing out laying schedules.

From our observations, and from those on injury-marked turtles made by others, we believe that a turtle interrupted in her nesting will return either later that night or on successive nights until she has fulfilled her mission. Carr and Giovannoli (1957: 24) reported for green turtles a similar "singlemindedness of the nesting drive," borne out by turtles number 111, G30, G37, G49, G115, and particularly by G43 and G102 (Table 2).

Thus a turtle tagged on a given date but not known to have layed then, can be assumed to have laid within the following few days, and any recovery of a turtle more than a week after the time of tagging theoretically constitutes an example of second nesting (see, for example, turtles number 118, 123, G33, G43, 147-G35 in Table 2).

In every case for which data are adequate, all the instances of multiple nesting on Jekyll Island took place at intervals of 12 to 15 days, with the single exception of number 114. With the 2-week interval between laying emergences shown so convincingly to be standard, it can be presumed that the other tagged animals would have shown comparable intervals had they been caught each time they nested. For example, recoveries of turtles 117 and 144, like the Florida returns noted above, probably represent second nesting emergences after tagging. Turtle 123 may have returned a third time. Turtle 136 definitely laid twice, and the interval between the time of tagging and first corroborated laying is long enough to have permitted a third nesting in the interim, or four nestings for the season. It seems likely that the turtles in the group discussed in the section on Group Emergence laid four times.

Sapelo Island, Georgia, is not considered a "good turtle island," and is not part of the Jekyll rookery. The minimum straight-line distance between the north end of Jekyll and the south end of Sapelo is approximately 19 miles. In 1958 three turtles were tagged on Sapelo Island, one of which (G23) was recaptured there 31 July, two nights after being tagged. She did not nest either time, but the return supports the popular assumption that each turtle nests on a single island, and only on that island, even though concentrated nesting may be going on at a nearby rookery. Another turtle, not tagged but bearing distinctive marks, apparently laid twice on Sapelo, on 18 and 28 June. The interval is short, but the evidence that the same turtle was involved is convincing, and we believe this to be another instance of multiple nesting on an island other than Jekyll. Little Cumberland Island, immediately south of Jekyll, seems from concentrations of tracks seen from the air to be part of the Jekyll rookery, but there is

no road to Little Cumberland, and no practical means were available to visit the island at night to look for turtles tagged at Jekyll, or to tag turtles for possible recovery at Jekyll.

Data extracted from a hitherto unpublished report (see Caldwell, 1959, herein) prepared in 1940 by William P. Baldwin, Jr. and John M. Lofton, Jr. show similar results for loggerheads tagged on a rookery at Cape Romain, South Carolina. These workers tagged 18 turtles as they came ashore to nest. Turtle number 4 was tagged but did not lay on 12 June; she was recaptured as she laid on 27 June. It is assumed that she laid soon after the 12th, and the expected 2-week interval between nesting ventures is indicated. Turtle number 13 was tagged but did not lay on 6 July. She was recaptured again not laying on 28 July. The elapsed time clearly indicates attempts at multiple nesting, perhaps three times in the 22 days. Turtle 10 was tagged on 3 July and recaptured on 4 July, nesting neither time. Turtle number 4 returned to a point 1000 feet north of the point of initial emergence; number 13, 950 feet southward; and number 10, 300 feet southward.

Unfortunately some of the people at Jekyll who furnished enthusiastic cooperation in tagging and in recording returns kept only dates of tagging and return and did not record the exact spots involved. It is of particular interest to note that in all cases where exact data were available for tagging and return, the turtle involved returned not only to Jekyll Island, but to the same portion of the island, within ¼ mile of the initial point of tagging on the 10.5-mile beach. None of the many turtles tagged at Jekyll Island was found by observers on Sapelo Island, nor were any of the few turtles tagged at Sapelo recorded as nesting later at Jekyll. The only returns on each island were turtles tagged on that island. Similar homing was noted by Carr and Giovannoli (1957) and by Hendrickson (1958) for the green turtle.

Evidence of Multiple Nesting Based on Unlaid Eggs

Data on egg size groups afford further evidence of multiple nesting and corroborate the tag return data.

Early in the 1957 season an individual designated as turtle A (Figure 20) that emerged on Jekyll Island 23 May was killed for study before being allowed to nest. She contained 120 shelled eggs of mature size (Carr, 1952: 391) she presumably would have laid that night. In addition to the mature eggs, a second group (II) of 182 eggs consisted of large yellow yolks, and a third group (III) consisted of

about 25 much smaller yellow yolks. Eggs of size group IV were tiny (4 mm. in diameter or less) white or yellowish spheres and occurred by the thousands. These tiny eggs presumably serve as a reservoir and may be present at all times in mature females. Since the 182 eggs in group II were more than the expected complement for a single laying, it was probable that some of the smaller ones in this group and the larger ones in group IV would have gone to build up the small group III to about the expected 125.

Another individual, designated as turtle B (Figure 20), was killed in mid-season on 1 July, also on Jekyll Island, just after nesting. She had deposited 144 eggs. The groups of smaller eggs in this individual were better defined than those in turtle A. The mature eggs of both turtles (group I in Figure 20) furnish definite evidence for one nesting that season. Considering the two turtles A and B as one composite animal, and postulating that nesting takes place at 2-week intervals, it is reasonable to assume that a laying by this hypothetical single turtle probably occurred between 23 May and 1 July. The group III eggs in turtle A might well have reached mature size in the elapsed month to become group I in turtle B. The fact that the nodes of egg diameters of groups II and III of turtle B are further advanced than corresponding ones in turtle A is further evidence that eggs develop continuously during the season to replace laid clutches of group I eggs.

While these data strongly suggested that multiple nesting occurs in loggerheads, they did not furnish firm grounds for calculating the number of times an individual might nest in a season, nor do the tagging results. One female might not come to the rookery until mid-season or later, and might nest only once or twice. Another might nest very early and thus have time to complete three or more additional layings. Turtle B in Figure 1, for example, might not have nested in early summer, and her egg-groups II and III may forecast two more nestings to take place late in the season. Or if she did nest early, they may represent a third and fourth nesting for the season. Conversely, her group III eggs might have been reabsorbed after the 1957 nesting season. Her group II eggs were large enough to have been destined for laying in the 1957 season, and it does not seem likely that any of her eggs of group IV would have reached maturity by the end of the 1957 season. Possible evidence that reabsorption of eggs occurs is the fact that some of the group III eggs in turtle B were dark purple or black in color as if vascularized for reabsorption.

In another instance turtle number G119 (Table 2) was killed after laying the second time. She had deposited 90 eggs in a normal fashion. Her oviducts contained 57 large yellow eggs approximately 14-30 mm. in greatest diameter which could have forecast a third laying for the season. There is no reason to believe she had not also laid 2 or more weeks before she was tagged. In addition to the large yellow eggs, she also contained about 200 whitish-yellow eggs 5-10 mm. in greatest diameter, and several thousand eggs less than 5 mm. in diameter.

Still another possibility is that the individual might complete a fixed number of nestings at 2-week intervals, no matter when she first arrives at the rookery. Thus, one group of turtles may nest early in the season (say 3 or 4 times during the first 6 weeks), another during the middle 6 weeks, and a third group during the final 6 weeks. As the laying season lasts only about 12 to 15 weeks, the groups of turtles surely overlap in their periods of stay, which could account for the larger number of turtles nesting in mid-season (see Caldwell, 1959, herein). More than three groups of turtles, or one turtle nesting more than three times, which our tagging studies suggest occurs, would further complicate such a nesting regime, but not make it impossible.

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William W. Anderson furnished us with valuable unpublished notes on Georgia sea turtles.

Seton H. Thompson and Richard T. Whiteleather of the United States Fish and Wildlife Service Bureau of Commercial Fisheries, and W. L. Towns and E. S. Jaycocks of the Bureau of Sport Fisheries and Wildlife were especially helpful in making available the unpublished reports of work done at Cape Romain, South Carolina.

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Literature Cited

Carr, Archie

1952. Handbook of Turtles. Ithaca, N. Y.: Comstock Publishing Associates, xv + 542 pp., 37 figs., 82 pls., 23 maps.

Carr, Archie, and David K. Caldwell

1956. The ecology and migrations of sea turtles, 1. Results of field work in Florida, 1955. Amer. Mus. Novitates, no. 1793, 23 pp., 4 figs.

Carr, Archie, and Leonard Giovannoli

1957. The ecology and migrations of sea turtles, 2. Results of field work in Costa Rica, 1955. Amer. Mus. Novitates, no. 1835, 32 pp., 13 figs.

Carr, Archie, and Larry H. Ogren

Manuscript. The ecology and migrations of sea turtles, 4. The green turtle in the Caribbean Sea.

Hendrickson, John R.

1958. The green sea turtle, *Chelonia mydas* (Linn.) in Malaya and Sarawak. Proc. Zool. Soc. London, vol. 130, pt. 4, pp. 455-535, 15 figs., 10 pls.

Lewis, C. Bernard

1940. The Cayman Islands and marine turtle. Bull. Institute of Jamaica, sci. ser., no. 2 (appendix), pp. 56-65.

III. THE LOGGERHEAD TURTLES OF CAPE ROMAIN, SOUTH CAROLINA[11]

Abridged and annotated by David K. Caldwell

Foreword: After the first manuscript in the present series was finished and submitted for publication, and after the field work for the second study was completed and the data partially processed, general inquiry revealed a manuscript dealing with loggerheads, dated 1940, in the files of the Regional Office of the United States Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Atlanta, Georgia. This manuscript, resulting from Service-sponsored research (then the Bureau of Biological Survey) by Service personnel, has been made available for publication now through the efforts of Seton H. Thompson, Richard T. Whiteleather, and William W. Anderson of the Bureau of Commercial Fisheries, and W. L. Towns and E. S. Jaycocks, of the Bureau of Sport Fisheries and Wildlife.

Although many of the findings presented in the 1940 report have been published independently by subsequent workers (almost surely without knowledge of the report), and although some of the topics are covered in the first two papers in the present series, it was felt that so much of the material represents completely new data that judicious trimming would produce a valuable contribution—one somewhat overlapping, but complementary, to work completed later. Because I was actively involved in field research on the loggerhead turtle and had knowledge of its natural history, it was felt that among those Service personnel interested I might be best qualified to develop the report into a publishable paper that would not overly duplicate findings already or soon to be published.

It should be emphasized that all of the field work was done by William P. Baldwin, Jr. and John P. Lofton, Jr., or by those they acknowledge, and that the report which came to my hands is entirely theirs. I have deleted parts that are repetitious with other studies, have added later literature citations and limited data from my own findings where appropriate (so indicated), and have redrawn those of their figures retained to conform with Bulletin style. In some instances I have rewritten sentences for smoother continuity where parts were deleted. For the most part the wording has been left as it was in their original report. I hope that in no place have I changed Baldwin and Lofton's meaning. "We" or "our" refer to Baldwin and Lofton. The 1940 manuscript has been returned intact to the Bureau of Sport Fisheries and Wildlife Regional Office in Atlanta, Georgia, where it is now on permanent file.

David K. Caldwell.
March, 1959

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[11] Contribution number 44 from the United States Fish and Wildlife Service Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia, and a contribution from the United States Fish and Wildlife Service Bureau of Sport Fisheries and Wildlife.

SYNOPSIS: Detailed field studies show that Atlantic loggerhead sea turtles, *Caretta caretta caretta* (L.), make exploratory crawls to the beach during nesting season, and the fact that a turtle is on the beach does not necessarily mean she will nest at that spot, although she apparently will nest in the immediate vicinity on the night she explores, or very shortly thereafter.

Evidence, contrary to popular beliefs, shows no correlation between nesting activity and the stage of the moon, tide, and weather conditions. The physical features of the beach are apparently the most important factors in determining degree of nesting activity.

The nesting procedure in South Carolina is consistent with that noted in other populations throughout the species' range.

Details of the nest and of the eggs, their incubation, and hatching are presented for future comparison with other species. An average period of incubation of 55 days is demonstrated in South Carolina, and a growth rate is given for the embryos. Many hazards, such as numerous kinds of predators, roots of vegetation, and unfavorable conditions of temperature and moisture are shown to exist for the eggs and hatchlings, resulting in a high rate of mortality.

Considerable variation in size, color, and body form is demonstrated for hatchling loggerheads.

Although South Carolina lies near the northern boundary of the nesting range of the Atlantic loggerhead sea turtle, *Caretta caretta caretta* (Linnaeus), the turtle nests abundantly there. This is especially true for the beaches of the Cape Romain Migratory Bird Refuge (McClellanville, South Carolina) where over 600 nests are made each season. This refuge, also a haven for bird colonies of many species, consists of three low barrier islands and the acres of salt marsh (*Spartina alterniflora*) which lie between them and the mainland. [Similar conditions exist in Georgia at the Jekyll Island rookery discussed by Caldwell, Carr, and Ogren, 1959, herein—D.K.C.]. The South Carolina islands, known as Cape Island, Raccoon Key, and Bull's Island, possess about 19 miles of ocean beach, most of which is potential nesting ground for the loggerhead. Bull's Island is wooded but Cape Island and Raccoon Key are not. The dune vegetation on all three is very similar. The commonest plants that grow there are beach oats (*Uniola paniculata*), cord grass (*Spartina patens*), and beach tea (*Croton punctatus*).

As far as we can ascertain, the loggerhead nests on the Cape Romain beaches in greater numbers than anywhere else on the Carolina coast. Cape Island with 5 miles of front beach has 400 nests a season; Raccoon Key with 8 miles has an estimated 200 nests; and Bull's Island, about 6½ miles long, has approximately 30 nests.

Work at Cape Romain

For several years notes on the loggerhead have been kept by personnel of the Cape Romain Refuge. In the summers of 1937 and 1938, under the direction of Andrew H. DuPre, Refuge Manager, Lofton worked on the north end of the refuge, and in 1938 Baldwin worked on the south end. During the summer of 1939 a more intensive study of loggerhead nesting was conducted, the writers [Baldwin and Lofton—D.K.C.] staying full time at Cape Island. Although most of this report is based on our 1939 work, we have drawn from the notes of our previous work, notes of Mr. DuPre, and from unpublished information contributed by the Charleston Museum staff and other local observers. Grateful acknowledgment is made to these persons for their helpful suggestions and material.

Size of Mature Females at Cape Romain

[Baldwin and Lofton made measurements and recorded weights of a few loggerheads at Cape Romain. The mean carapace length for 18 turtles was 36½ inches, with a range of 33¼ to 40½. These results compare favorably with those made at Jekyll Island in 1958 and reported by Caldwell, Carr, and Ogren, (1959, herein). Baldwin and Lofton found the following relationship between weight and carapace length: 33¼ inches in carapace length, weight 193 pounds; 35¾, 218; 36½, 262; and 39, 298. Another individual with a carapace of approximately 35 inches weighed 257 pounds. Baldwin and Lofton report a skull in the Charleston Museum (catalog number 2373) reportedly taken from a South Carolina loggerhead turtle that weighed 607 pounds. They also state that a McGowan Holmes of Edisto Island, South Carolina, reported to the Charleston Museum in 1935 that the largest loggerhead of the many he had observed in that section had a carapace measuring 48 by 38 inches.—D.K.C.]

Length of Stay by Turtles at Cape Romain

In March the adult turtles appear in the bays and salt creeks which wind through Romain's marshes in all directions. Although previously they had been seen early in March, the first appearance recorded in 1939 was on 28 March. The first mating pair was observed in Cape Romain harbor on 31 March. It is during April and May that the turtles appear most frequently in the bays and creeks behind the islands. During this time mating couples are seen commonly, and often several males may be observed following or even clasping the

same female. The latest recorded mating in 1939 was on 11 May, although it certainly was not the latest occurrence. In that summer, egg-laying commenced in the middle of May. During June, July, and August, when the adult females are laying on the front beaches, turtles are not commonly seen in the creeks, and we have no records of mating in those months. By October most of the adult turtles have disappeared.

Mating

We have records of mating for every hour from dawn to dark. Night mating doubtlessly occurs, but we have no information on the duration of copulation. As is the case with other species of marine turtles, paired loggerheads may copulate for extended periods and perhaps the females remate after each nest is made.

Mating turtles float in the water with the male in the superior position. While the female is submerged completely, the highest part of the male's carapace is usually out of the water. The head of the male emerges for breathing every few minutes, and the female struggles to the surface for air about every 5 minutes. With his plastron on the female's carapace, the male holds immovably to her with all four limbs, thus leaving the female free to swim. The very large tail of the male, which is 8 inches or longer, bends down pressing the cloacal opening against the similar organ of the female, and the two are tightly joined.

Nesting

Duration of Nesting

On Cape Romain's beaches nests are made from mid-May to mid-August. When work was begun at Cape Island on 19 May 1939 a few nests had already been made. The last nest was made there on the night of 18 August. Thus the laying season extended over a period of 3 full months with its peak in June and July. [A similar season was found at Jekyll Island, Georgia—D.K.C.].

Nesting and Non-nesting Crawls

The crawling of the turtle on the beach does not necessarily signify that the animal has made a nest. If the site does not appear favorable, the turtle often returns to the water without laying and usually tries again farther down the beach. In our counts we differentiated between nesting and non-nesting crawls. Each morning we patrolled the entire 5 miles of beach and recorded the preceding

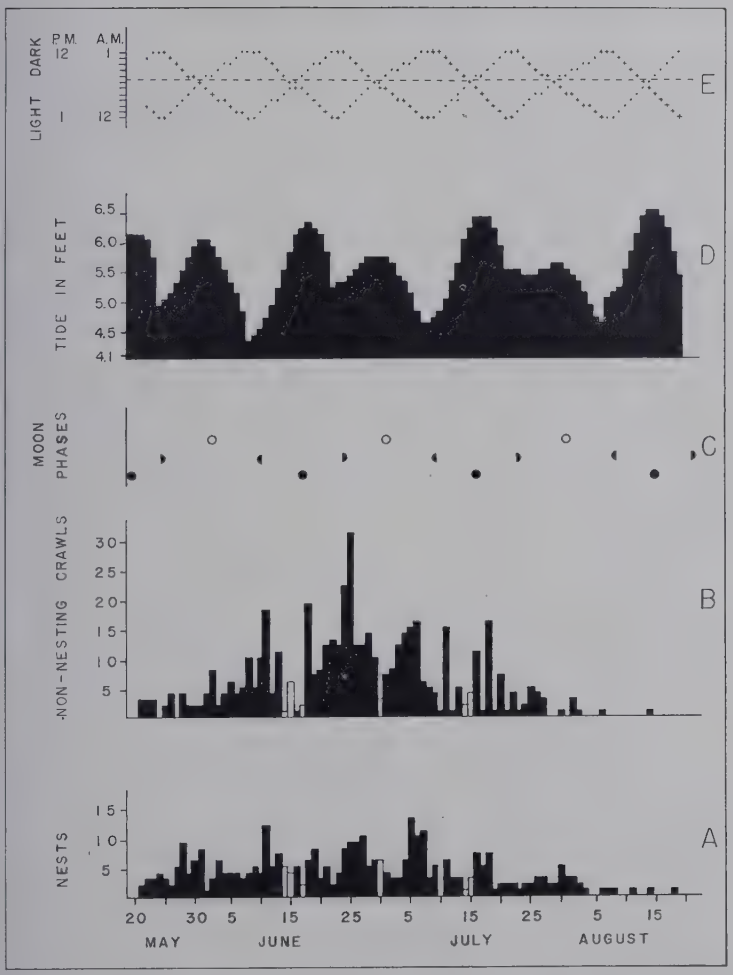

Figure 21.—Nightly number of loggerhead turtle crawls with correlated tidal and lunar conditions at Cape Romain, South Carolina, in 1939. The dates apply to all sections of the figure. Section A represents the total number of nests made each night (solid bars indicate total counts, open bars indicate that all crawls may not have been recorded for that date); Section B represents the total number of non-nesting exploratory crawls (bars as in A); Section C represents the phases of the moon, with solid symbols indicating new moon and open circles full moon; Section D represents the highest P. M. tides for the date; Section E represents the time, to the closest hour, of high tide (+ represents A.M., ° represents P.M.; symbols above the dashed line represent dark hours, those below indicate daylight hours).

night's nesting and non-nesting crawls. This information is presented in Figure 21. Complete data for the first few days on the island are not available and the information presented starts on 21 May. Except for the nights indicated, the nightly number of crawls is complete; those thus marked indicate that extremely high tides and blowing sand may have obliterated some of the crawls before we reached them.

The greatest number of nests made on any night was 13, and the nightly average for the 90-day period was 3.8. The greatest number of non-nesting crawls made on any night was 31 and the average (90-day) was 5.3. As is indicated in the figure, there is a fairly close correlation between the nightly numbers of nesting and non-nesting crawls.

Correlation of Crawls with Lunar and Meterological Data

Also included in Figure 21 are the daily records of tidal and lunar phases which would possibly affect nesting activities. These will be discussed separately.

Moon phase. It is a common local belief that the greatest nesting activity occurs during the period of the full moon. In Figure 21 the moon phases are diagrammed in relation to the number of crawls, and we can find no correlation to justify this belief. The peaks of egg-laying occur during all phases of the moon, and such peaks appear to be about 10-13 days apart.

Monthly range of tide. Assuming that turtles can hold their eggs for short periods, one might imagine that most turtles would put off laying until that time of month when tides are highest. In this manner they could utilize the higher water to float in nearer to the dunes. As Figure 21 shows, however, there was no correlation between height of tide and egg-laying. In that section the tides given are those which occurred from 12 noon to 12 midnight and are projected tides presented in the Coast and Geodetic Survey tables (1939).

Time of high tide. As loggerheads begin their nightly crawling just at dark, one might assume that most turtles would lay on those nights when the high tide, regardless of its height, was reaching its peak just at dark. No such correlation was found.

In speaking of the Bermudian sea turtles in general, Babcock (1937) mentions that they come ashore to deposit their eggs on a rising tide. McAtee (1934), in writing of the loggerhead (apparently in Georgia and other southeastern states), also mentions that the females come ashore chiefly on the rising tide. At Cape Romain, however, the loggerheads started coming ashore just after dark whether the

tide was high or low, and most of the activity was in the first 4 or 5 hours after dusk. This information was gathered by nightly patrols of certain stretches of beach and rechecked on the morning patrol.

Other factors. Although no barometric readings for the Cape Romain area were available, comparison with Charleston data indicated no correlation. The nesting of turtles was little affected by minor storms or even easterly squalls. In one instance, however, on the night of 10 July, a severe thunder storm which started just after dark and was followed by an all-night rain may have been responsible for the lack of turtle activity; no nests were made that night and only one non-nesting crawl was observed, although there was much activity on the preceding and following nights.

The highest daily air temperatures throughout the laying season ranged between 81° F. and 97° F. The lowest daily temperatures ranged between 66° and 79°. There was no correlation between air temperature and nesting activity. Likewise, there was no apparent relationship between wind direction or velocity and turtle crawling.

Selection of Nesting Sites

The Cape Island beach during the summer of 1939 offered six kinds of potential nesting sites to female turtles. Figure 22 shows these beach types in cross section and we have given them descriptive titles:

A. *Truncate dunes*: Sharply eroded dunes backing a beach 5 to 10 feet wide on an average high tide. Extremely high tides pounded the base of these dunes. Turtles never were able to ascend the face of these, although they often tried. The truncate dunes graded into the next type.

B. *Ledge section*: A stretch of beach that had a ½- to 3-foot ledge breaking the middle of its natural slope. This type was variable and was formed by the action of wind and tide. At times the ledge was high enough to prevent the turtles reaching the dunes to nest [see Caldwell, Carr, and Hellier, 1956.—D.K.C.].

C. *Wide sloping beach*: 25 to 40 feet wide from average high tide line to base of dune. The outer dune was a continuous ridge which paralleled the ocean front and was broken in only a few places. Turtles could easily crawl from the surf to the base of the dunes.

D. *Narrow flat beach*: 10 to 20 feet wide and backed by small separated dunes. Turtles could often climb these dunes or go through the gaps between them.

E. *Wide flat beach*: Similar to the narrow flat beach, 30 to 50 feet wide and backed by small isolated dunes.

F. *Barren areas*: Stretching 100 to 400 feet back from the crest of the beach, with only traces of vegetation or low dunes to break their flatness.

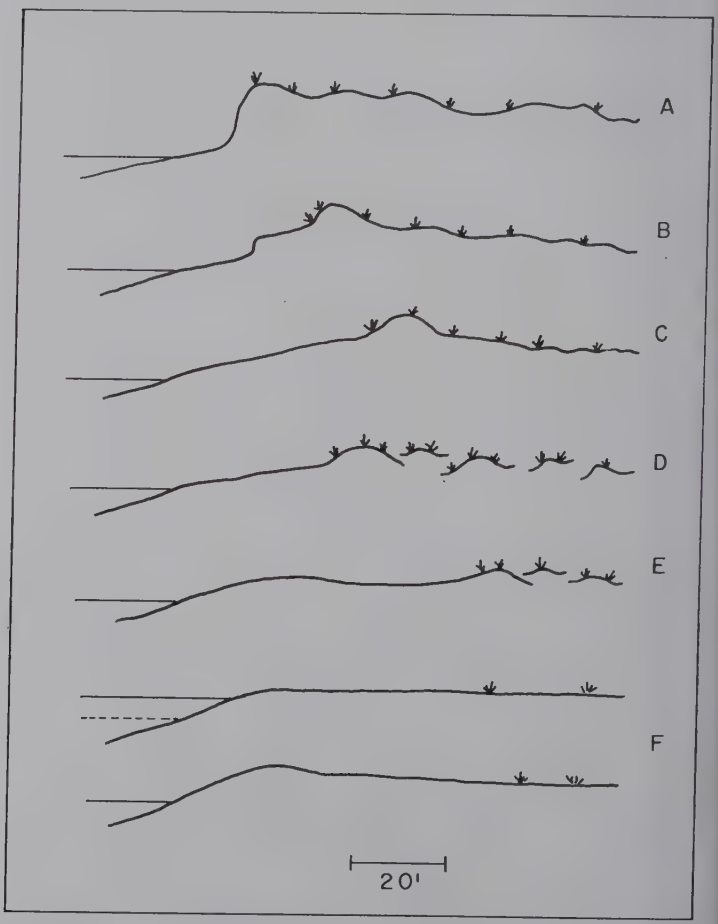

Figure 22.—Diagramatic cross sections of beach types at Cape Island, South Carolina, in 1939. See text for details.

The Cape Island beach, in general, is much narrower and steeper than those of Raccoon Key and Bull's Island, and the sand is coarser. The beach at Cape Island is by no means stable, but is constantly cutting away and building up. Remains of nests made in 1938 were noticed in 1939 to be on top of truncate dunes 15 feet high, which indicated considerable cutting away during the winter between these two nesting seasons. Observations in the first part of the summer of 1940 show that the beaches have changed again. In fact, the truncate dunes of 1939 have been changed into a wide sloping beach of 1940 by the deposition of sand at their base so this stretch of beach which was so unsuited for turtle nesting in 1939 is an ideal type in 1940, and contains an abundance of crawls.

Just as certain types of beach appeared to our eyes more favorable than others for nesting, so did they to the turtles. Data to substantiate this, based on the location of 343 nests and 463 non-nesting crawls, are offered in Table 3.

Some of the most interesting facts that can be deduced from the information presented in Table 3 are those relating to turtle behavior in selection of nest sites. What process of thinking makes a turtle leave the truncate dunes without nesting and swim farther along the shore to nest on the wide sloping beach? Such things happened. In the truncate dunes one nest was made every 197 feet of ocean front and one non-nesting crawl every 32 feet; for every turtle that laid on this low beach, six turtles returned to the surf without laying. On the high wide sloping beach, however, turtles made one nest every 28 feet, and one non-nesting crawl every 55 feet. For every turtle that nested, a theoretical half of a turtle returned without nesting. Thus this high type of beach backed by rounded dunes (see Figure 22) was chosen by turtles more often than any other type. With its 1 nest every 28 feet, compare it to the barren area with its one nest every 204 feet. This is further evidence that low dunes backing a high beach increase its desirability as a nesting site.

Other factors, such as the amount of moonlight, probably influence the turtles in selecting various types of beach, but to what extent we do not know. Statistical data, which will not be presented here, indicated that throughout the season there was no important shifting of turtle nesting from one type of beach to another. [Aerial reconnaissances of all of the beaches of Georgia and most of those of North Carolina, South Carolina, and the Atlantic coast of Florida have indicated that nesting turtles show a preference for a beach backed by high dunes or vegetation, which thus presents a dark and broken

TABLE 3

NUMBER OF NESTING AND NON-NESTING CRAWLS MADE BY ATLANTIC LOGGERHEAD SEA TURTLES ON EACH TYPE OF BEACH AT CAPE ISLAND, SOUTH CAROLINA, IN 1939.

Beach Type	Percent of total beach	Total feet of beach	Number of nests	Number of feet of beach per nest	Number of non-nesting crawls	Number of feet of beach per non-nesting crawl	Number of feet of beach per both types of crawls	Ratio of nesting crawls to non-nesting crawls
Truncate Dunes	7.0	1970	10	197	61	32	28	1 to 6.1
Ledge Section	7.9	2223	40	56	61	36	22	1 to 1.5
Wide Sloping	11.0	3096	110	28	56	55	19	1 to 0.5
Narrow Flat	7.8	2195	55	40	62	35	19	1 to 1.1
Wide Flat	16.3	4587	59	78	38	121	47	1 to 0.6
Barrens	50.0	14071	69	204	185	76	55	1 to 2.7
TOTAL	100.0	28142	343		463			
AVERAGE				82		61	35	1 to 1.4

horizon to a turtle in the water instead of the lighter and relatively unbroken outline offered by sand flats or the open ocean. This may be one factor in drawing the turtles to such beaches. To turn seaward or along the shore to the light, unbroken, horizon would of course be disadvantageous to a turtle trying to land to nest. The apparent hesistancy for a turtle to strand on a barren flat may be a secondary result of this same phenomenon of relation to horizon, rather than some physical factor of the barren beach itself.

In an analysis of distance crawled by nesting and non-nesting females in relation to the type of beach, Baldwin and Lofton found that the turtles prefer to nest on high beaches near or in the dunes, beyond the reach of the tide. In addition, on large barren sand flats where turtles may crawl hundreds of feet back from the ocean, they prefer to lay only 1 to 30 feet from the crest. They found that adult turtles crawling far back on these barrens often became confused and wandered hundreds of feet in all directions before locating and reentering the ocean. Therefore, nesting close to the ocean not only guarantees a safer journey for the young when they hatch, but also insures the adults' safe return to the surf.—D.K.C.]

Primary Excavation

When the turtle finally has selected a desirable nesting place, she makes a primary excavation. This is a shallow depression, larger than or approximating the size of the turtle, made by the turtle's movements. The turtle moves the posterior end of its body from side to side and pushes the sand out with its hind flippers, often making the middle of the excavation a foot deep. This primary excavation is largely exploratory, and often the turtle will move on farther and dig again if the site does not suit her. Turtles made this primary excavation in 23 percent of their non-nesting crawls; in the best type of nesting site, the wide sloping beach, it was made in 46 percent of the non-nesting crawls. In the truncate dunes, one of the least desirable sites, it was made in 13 percent. In short, those beach types that had the most nests per unit of ocean front likewise had the most investigation, as indicated by primary excavations by non-nesting turtles. Several factors are responsible for the abandoning of these primary depressions. An obvious one had to do with the conditions affecting digging, namely: sand packed too hard, sand too dry and soft, layers of oyster shells, and an abundance of tough vegetation roots. Another factor was position in relation to tide, for sites well above the average tide level are preferred. [It is presumed, though not

stated, that all nesting females made the primary excavation as was the case during 1957-58 studies on the Jekyll Island rookery.—D.K.C.]

Secondary Excavation

[Here Baldwin and Lofton cite the work of others as being representative of their own findings. An illustrated description of the process is presented by Caldwell, Carr, and Ogren, (1959, herein). One comment by Baldwin and Lofton, also noted on several occasions at Jekyll Island in 1958, concerns repeated secondary digging by a turtle. They state that just as the hardness or the caving in of the sand or the presence of vegetation roots affect the primary excavation, so do they often cause the turtles to cease digging the egg hole. In one site examined, the female had dug eight holes and still had not laid her eggs.—D.K.C.]

Laying and Covering the Eggs

[This process, while described by Baldwin and Lofton, has been discussed in detail and illustrated by Caldwell, Carr, and Ogren (1959, herein).—D.K.C.]

Return to the Sea

After covering the nest, the turtle is ready to return to the sea. Of the 350 nest sites examined, in only one instance did we find that a turtle had paused on the return crawl to make excavations similar to those normally made before digging the egg hole. In returning to the sea the female is somewhat exhausted and usually makes frequent stops to rest. One turtle that had not been disturbed crawled the 180 feet to the sea in 25 minutes. Another undisturbed turtle traveled the 50 feet to the surf in 3 minutes. The strength of these turtles is illustrated by the fact that one which had just finished laying carried two of us to the ocean on her back—a weight of about 275 pounds.

Not infrequently turtles nesting at Cape Romain became lost on the return to the sea. This occurred on two types of beaches, flat barren areas and those backed by isolated dunes. These barren areas, from 200 to 400 feet across, gradually slope back from the crest of the ocean beach making the ocean invisible to a turtle 50 or 60 feet inland. One turtle, after making four primary excavations, moved inland, became lost, and wandered extensively for 2,140 feet over the sandy flat. Another turtle, also on a barren area, apparently made several small circles after nesting to determine her position with respect to the sea before she returned to the water. A third indi-

vidual nested well back from the crest of the beach in the barren area, and on completing her nest crawled diagonally back to the crest of the beach to a point where she could see the beach. For some undetermined reason she then reversed her direction and crawled for several hundred more feet around the barren area before returning to the water. Such action was most unusual. A fourth turtle became confused among a group of isolated dunes. She nested on the top of a 10-foot dune 100 feet from the ocean. Upon descending the dune, she could not see the ocean and wandered extensively among the 2- to 5-foot dunes, never climbing any of them, until eventually she reached the safety of the ocean beach. An occasional loggerhead skeleton far back among the dunes is mute evidence that turtles do remain lost until the merciless heat of the rising sun kills them.

Description of the Nest

Position of the Egg Deposit

When the laying turtle has returned to the sea, its tracks lead to a nest site that is easily recognized by the churned up sand and crushed vegetation. This area, if located in dune vegetation which hampers the movements of the turtle, is usually circular and 4 or 5 feet in diameter. In sites lacking plant growth, the muddled areas are oval to oblong, and may reach a size of 6 by 25 feet. The exact position of the nest in all this muddling may appear difficult to locate, but with a little practice one can soon pick out the exact spot. To us it appeared that the egg deposit was usually near the fore, or entrance, edge of the muddling and equidistant from either side.

Depth of Eggs

The cavity the eggs fill is 6 to 10 inches deep, 8 to 10 inches wide, and slightly wider at the bottom than at the top. This egg deposit is found at varying depths. The depth of the top eggs in 317 nests ranged from 5 to 22 inches, with two-thirds of them between the 11- and 16-inch levels. This agrees with the depths of six North Carolina nests measured by Coker (1906). As already mentioned, fresh nest sites in open sand present a different appearance from those in dune vegetation, and it was thought that the depth of the egg deposits might correspondingly be affected. Distribution of the data according to the various degrees of cover, however, revealed only a slight tendency for nests in the dune vegetation to be a bit shallower than those on the edge of vegetation or on open beaches. The ex-

treme depths were reached only by turtles making unusually deep primary excavations, and egg holes as deep as possible, with the eggs covered by sand to an extraordinary height. In conclusion it might be mentioned that the egg deposits laid at the last of the season were buried just as deeply as those first laid. Furthermore, there was no apparent correlation between the depth of the eggs and the chances of sand crab depredation (see below).

Sand Conditions

The sand piled over the fresh egg deposits is usually reduced 1 to 2 inches during the incubation period by wind and tide action. Obviously this erosion and subsequent obliteration of the site decreases the chances of nest depredation.

The sand over the nest, as left by the turtle, is firmly packed immediately above the eggs and loosely piled above that. As incubation proceeds and the eggs settle, an air space often forms between this packed sand and the top eggs. Many times, by the time the young turtles have hatched, this space has grown to be a small domed chamber. If the arch of this chamber collapses and the sand falls upon the eggs or young, a small but noticeable surface crater results. This probably is easily found by foraging sand crabs [or raccoons—D.K.C.] to the detriment of the nest.

Eggs

Number Laid

A study of 71 nests throughout the laying season revealed clutch sizes ranging from 64 to 198 eggs, with an average of 126.

Six nests examined by Coker (1906) in North Carolina contained 118 to 152 eggs. Alexander Sprunt, Jr. has checked the number of eggs in loggerhead nests for many years in the Charleston section. His three highest counts were 180, 219 (Raccoon Key), and 341 (Sullivan's Island). Marshall Alston, a negro fisherman who formerly collected and sold the eggs from hundreds of Cape Romain nests, reported that the smallest clutch he ever found contained 65 eggs and the largest 280.

Relation Between Number and Time of Season

Several authors have pointed out that it was "believed" that the loggerhead laid several clutches a season, the number of eggs per clutch decreasing each successive time. [It has now been shown (Caldwell, Berry, Carr, and Ragotzkie, 1959, herein) that individual

loggerheads do nest several times a summer.—D.K.C.] We have analyzed the clutch size for 71 Cape Romain nests according to the time of season laid. It appears that the number of eggs does decrease as the season progresses. [A similar analysis of 26 clutches at the Jekyll Island rookery in 1958 produced the same results.—D.K.C.].

Size of Eggs

The measurement of 827 eggs taken from 44 nests the day after they were laid revealed that the greatest diameter of normal eggs ranged from 35 to 49 mm., with an average of 41.5 mm. Loggerhead eggs, when laid, appear perfectly round. Many of the measurements were secured by measuring only the 5 top eggs in each nest. This sampling avoided handling of whole clutches and the subsequent effect on percentage of hatch. Some nests were completely excavated and the entire clutch measured and weighed. The total weight of 119 eggs in one nest was 4,155 grams, or an average weight of 35 grams per egg. The variation of egg diameter within a clutch ranged from 3 to 11 mm.

Size of Eggs in Relation to Order Laid

Further investigation of egg size variation revealed that, within the clutch, the eggs laid last were smaller than those laid first. This was determined by the measurement of six freshly-laid clutches. The resulting data are presented in Table 4. The eggs were measured as they were removed from the nest and each group of 20 is composed of eggs deposited in the same layers and within the space of a few minutes or, in short, in the order that they left the female's body. The groups of 20 are arranged in the table with the eggs found in the top of the nest (laid last) at the top of the column, and in descending order through the nest to those in the bottom (laid first).

That the eggs laid last would be smaller than those laid first seems natural if one considers their relative position to the many undeveloped eggs that remain in the turtle's egg tubes. All these measurements were made the morning after each nest was made and the possibility of nest pressure affecting these diameters may be largely disregarded for the eggs were in no way misshapen. Moreover the range of variation within each layer was additional evidence that the size differential was natural.

Eggs of unusual sizes are occasionally found in nests. Small yolkless eggs 28 to 30 mm. in diameter are one type and may represent

the last eggs laid by a turtle. On the other extreme, abnormally large eggs are occasionally found. One egg, almost hen-egg shaped, measured 51 by 43 mm. when laid. Another, with two yolks, measured 66 by 47 mm.

TABLE 4

RELATION OF EGG SIZE TO ORDER OF LAYING IN THE ATLANTIC LOGGERHEAD SEA TURTLE AT CAPE ROMAIN, SOUTH CAROLINA, IN 1939. MEASUREMENTS ARE THE AVERAGE DIAMETERS IN MILLIMETERS.

Relative position of eggs in nest	Nest Numbers					
	294	295	322	331	337	346
20 laid last (top of nest)	39.8	37.7	40.4	41.4	45.1	43.8
20	40.6	38.4	40.6	42.6	45.7	44.3
20	41.2	38.8	40.7	42.7	45.9	43.9
20	42.3	39.2	40.7	42.7	45.4	43.9
20	43.6	39.4	40.7	43.1	—	44.0
20 laid first (bottom of nest)	—	40.2	40.9	—	—	—
Average diameter	41.5	38.9	40.7	42.5	45.5	43.9

Egg Size in Relation to Adult Size

A definite correlation between the size of the eggs laid and the size of the turtle was noticed. In seven instances in which the carapace lengths of the adult turtles and the average diameters of their eggs were known, it was found that the larger the turtle, the smaller the average size of her eggs.

INCUBATION

Development of the Embryo

From embryo measurements secured through periodic examination of two nests, a composite growth curve has been constructed (Figure 23). Macroscopic examination of opened eggs revealed no embryos for the first 2 weeks, but on the 14th day embryos about one millimeter long were observed in several eggs. From then on growth

was rapid. When examined on the 26th day the embryos were pale grayish blue and showed movement, and by the 32nd day they were very active and their eyes were open. Fifty-four days elapsed between the night of egg-laying and the appearance of the turtles on

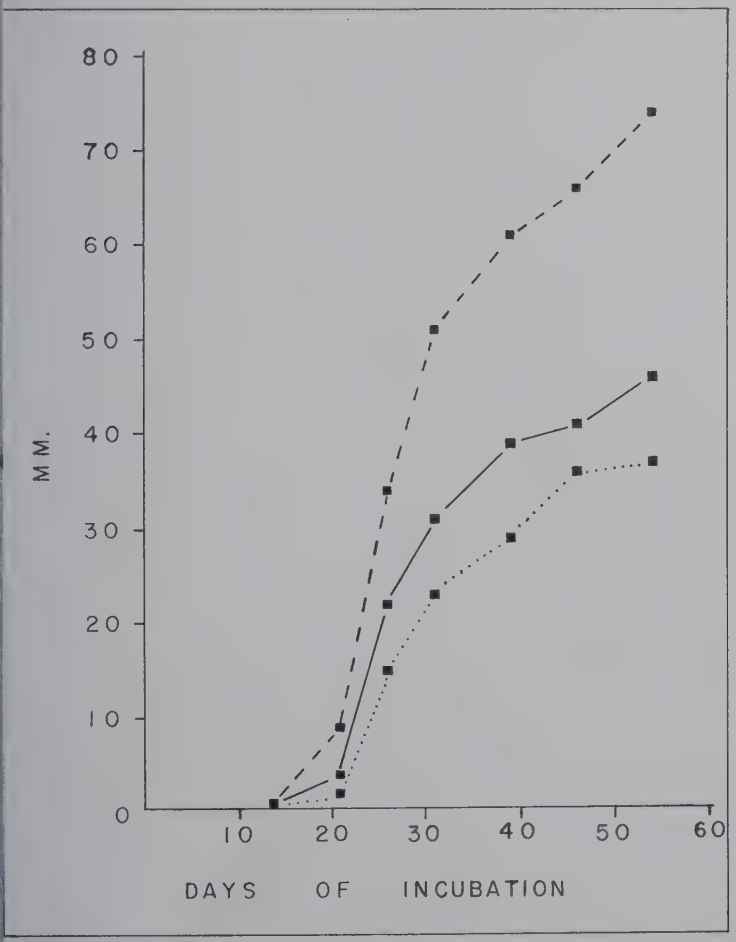

Figure 23.—Composite growth of loggerhead turtle embryos from two nests at Cape Island, South Carolina, in 1939. Dashed line represents total length, solid line represents carapace length, dotted line represents carapace width. The average diameter of the five top eggs when laid in each nest was 41 mm.

the beach. Hatched and developed turtles, however, were down in the egg deposit on the 51st day and perhaps earlier.

During incubation one of the most obvious external changes that occurs is the "whitening" of the egg shells. When deposited, the creamy white eggs are bathed in a clear secretion which causes them to glisten. This soon evaporates and the shells gradually whiten. Several nests made in August were examined periodically and it was found that on the second day of incubation the majority of the eggs throughout the deposit had small round white marks on their "tops", with a few eggs having them on the sides, and none on the under surface. By the end of the first week of incubation the whitening of each shell was three-fourths to nine-tenths complete, and was proceeding at the same rate for all depths of the egg deposit. At this stage the small remaining unwhitened areas were all on the under surfaces of the eggs. By the end of the second week the shells were completely white, and this probably had occurred about the 10th or 12th day. This drying and hardening of the egg shell, which proceeds uniformly regardless of the location in the egg deposit, points to a uniform heat distribution and incubation rate throughout the nest. The shells of infertile eggs do not whiten in this manner, but by the end of several weeks have acquired a deep creamy color.

Another obvious change is the gradual swelling of fertile eggs as incubation proceeds. The absorption of soil moisture is responsible for this. The total length of the fully developed embryo just before hatching is greater than the largest diameter of the freshly laid egg.

Incubation Time

The length of incubation was considered to be that period beginning with the egg laying and ending with the appearance on the surface of the main group of young turtles. For 55 Cape Island nests this ranged from 49 to 62 days, and the average period was 55 days. [Caldwell, Carr, and Hellier (1956) found incubation periods in Florida as long as 68 days under somewhat unnatural conditions of handling and habitat—D.K.C.]

Factors Affecting Incubation

Some half dozen factors might be considered as possibly affecting the incubation length: Sunlight and shade, nest temperature, depth of egg deposit, soil type, moisture content of the soil, and tidal and underground water level conditions.

Sunlight and shade. Incubation periods of nests made at the first of the laying season (last of May) and those made at the last of that season (last of July) were found to be longer than those for nests made in the middle of the season. This, it was felt, was due to the total amount of heat received by these nests. This heat factor depended upon possible hours of sunlight, the actual hours of sunlight, and the range of air temperature. Data for the Charleston area supplied by the U. S. Weather Bureau indicate that the possible hours of sunlight at the start of the laying season (middle of May) was 14 hours per day, rising to 14.3 through June, and gradually dropping to 12 hours by the end of September (practically the incubation season). The actual hours of sunlight, however, were much lower than the possible hours: 64 percent in May, 60 percent in June, 75 percent in July, 61 percent in August, and 57 percent in September. The average daily air temperature was closely correlated with the actual hours of sunlight, those periods experiencing the most sunlight also having the highest temperatures. The temperatures through the last of June, July, and first of August averaged higher than those at the first and last of the incubation. In short, incubation periods shortened as the temperature and amount of sunlight increased.

Additional information on the relation of incubation length to the amount of sunlight is supplied by the following observation by Mr. Chamberlain of the Charleston Museum. He collected 12 eggs from a nest made on Cape Island on 6 June 1927. Placed in a box of sand, these eggs were kept in a warm garage and occasionally sprinkled with water for 2 weeks. They were then removed to a location where they received 2 hours of sunlight daily. On 16 September, 102 days later, the eggs were uncovered and it was found that, of the two hatched turtles, one was still alive and of normal dimensions. This extreme length of incubation caused by unnatural conditions was no doubt largely due to the absence of sufficient sun heat.

Under natural conditions shading is caused by dunes and thick vegetation. In analyzing the incubation lengths of specific nests in relation to natural conditions of sun exposure, tide, and depth of egg deposit, it was found that for the most part the data further illustrated that the incubation period varies with the amount of sun heat.

Nest temperature. As determined by a fairly extensive series of thermometer readings taken under all conditions of weather, the temperature within the nest is subject to less fluctuation than the surface temperature. Thus, while our extremes of daytime surface temperatures ranged from 74° to 128° F., the temperature within the egg

deposit fluctuated only from 77° to 93° F. In fact, the egg deposit temperature usually remained between 82° and 88°, and the 77° reading was recorded only after a 3-day rain. The constancy of temperature within the nest was maintained not only during the day but also at night, even though the surface temperature might then fall considerably. The maintenance of a stable temperature appears to be a requirement for a normal incubation length. Of course the temperature decreases with an increase in the depth at which readings are taken, but in the normal depth range of loggerhead nests this is a matter of only 1 or 2 degrees.

Depth of eggs. It will be recalled that at Cape Island there was considerable range of depth for eggs in different nests. To determine whether the depth of eggs affected the incubation length, one fresh nest was excavated and groups of eggs from all parts of the original deposit were reburied at varying depths under similar environmental conditions. On the 55th day of incubation the young were out of the eggs in all the levels from 12 to 30 inches. From the relative position of the young it may be assumed that those in the shallower depths hatched slightly before those in the greatest depths. Twenty-four hours later they had reached the surface from the shallowest deposits, but from the extreme depth they did not reach the surface until 8 days later. Therefore the depth does not greatly affect the actual length of incubation, but only the time required for emergence. It is of additional interest to point out that the young from the 12 smallest eggs in this clutch, which were buried together at the 15-inch level, were on the surface on the 54th day, or 2 days before the young from average-sized eggs at the 15-inch level had reached the surface. This may indicate that small eggs hatch before large eggs of the same clutch.

Soil type and moisture content. Two closely related factors that doubtless affect incubation are the soil type and moisture content. On the Cape Island beach the soil types varied from crushed oyster shell to fine sand. The latter is usually very dry. Three types of sand were assayed for moisture content. These samples, taken from below the surface, were typical of the majority of nest sites. The moisture contents were determined by Dr. Horatio Hughes of the Department of Chemistry of the College of Charleston, and are presented below:

1. Fine sand at the base of dunes in *Uniola paniculata* roots 1.3%
2. Beach sand at the base of truncate dunes 3.1%

3. Coarse sand from barren flats among isolated dunes 4.2%

The above figures are the percentages of moisture by weight. Sand taken from the site of one North Carolina nest by Coker (1906) contained 3.8% water.

Underground water level and tide. Although the layer of sand on the surface is dry as a result of evaporation, the sand a few inches below is damp, and this condition extends down to the underground water level. To the touch this sand is moist and cool when compared with that at the surface. On top of the dunes the upper layer of dry sand appears to be thicker than at the base of the dunes or on flats. In all of the above sites loggerhead nests experience normal incubation, and it appears that the optimum moisture content would be 2 or 3 percent. In nests in low areas where the tide not only can cover the nests frequently but also raise the underground water level around the eggs, the incubation period is lengthened. In one Bull's Island nest so situated in 1938, the sand was so wet that earthworms (*Lumbricus*) were found in the deposit, and the incubation period, as based on the only turtle that hatched, was 80 days. The effect of water on the percentage of hatch will be discussed later.

Hatching

Escape from the Egg

As the end of the incubation period nears, the eggs have increased considerably in size through the absorption of water. The curved embryo, which completely fills the egg, develops a sharp point on the snout just before hatching. The combination of the increased internal pressure and the use of the egg tooth facilitates the escape from the egg shell. The pipping and escape from the eggs occur in all levels of the egg deposit almost simultaneously. In one nest we examined the turtles were just pipping the eggs on the 48th day of incubation; they had egg sacs measuring ¾-inch by 1 inch, and their carapaces did not appear to be fully grown. On the 55th day the fully developed young, without trace of the egg sac, appeared on the surface of the beach. The shortest period of actual incubation we recorded was one in which the young were pipping the eggs on the 45th day. In general, the external egg sac has been completely absorbed shortly after the young have escaped from the eggs, although it may occur before this act has been completed.

Escape from the Nest

Internal egg yolk must nourish the small turtles during their upward struggle through the sand; while this climb of 1 to 2 feet may take only 1 day, the average time is 2 to 3 days, and not uncommonly as long as 5 or 6 days.

Young loggerheads usually appear on the surface at night, which prevents their being killed by the heat of the daytime sun. The intensity of heat is probably the factor controlling the time of this egress, for turtles found 1 to 4 inches under the surface in the middle of the day were inactive, but emerged in the cool of the following night. In the few instances where turtles reached the surface during the day they appeared stupified by the surface heat which soon kills them. Turtles removed from the depths of a nest during the day, however, and released on the beach easily reach the water before being affected.

Just as the turtles escape from the eggs more or less together throughout the nest, most of them arrive at the surface during the same night. Those climbing up first loosen the sand and make the way easier for the last of the hatch. Sometimes the escape from the nest will last a week, with the main emergence preceded or followed by successively smaller numbers.

Percentage of Hatch

The percentage of hatch, based on 62 nests, is presented in Table 5. The nests are divided into groups according to relation to tide exposure and presence of vegetation roots. Not only are the averages presented, but also the range of hatchability for each type. The range indicates that some nests will be highly unsuccessful no matter how favorable their location. The average hatch was 73.4 percent. Eggs that did not hatch were opened and examined macroscopically; some of those considered as having no development may well have contained extremely small dead embryos. As Table 3 shows, however, 20.7 percent of all eggs were infertile, and 3.8 percent contained embryos that died in various stages of development. One interesting discovery was that 5.3 percent of the eggs laid among *Uniola paniculata* were destroyed by its roots. The hair roots formed thick mats around the individual eggs, eroded the shells, and desiccated them; often the sharp-pointed stolons pierced the eggs. A small number of the turtles that pipped their eggs were unable to completely escape the shell and died. Still another small percentage escaped from the

PERCENTAGE OF HATCH, BASED ON 62 ATLANTIC LOGGERHEAD SEA TURTLE NESTS UNDISTURBED BY PREDATORS OR EROSION, AT CAPE ISLAND, SOUTH CAROLINA, IN 1939. FIGURES REFER TO PERCENTAGE OF TOTAL EGGS IN CLUTCHES LAID IN EACH OF THE FIVE SITES (SEE TEXT FOR EXPLANATION OF TYPES OF BEACH).

		Open, Exposed Sites		Base of Dunes		On Dunes in *Uniola* roots	Average
		Occasionally covered by tide	Never covered by tide	Occasionally covered by tide	Never covered by tide	Never covered by tide	
Successfully hatched	Mean:	66.9	73.3	86.7	82.4	65.3	73.4
	Range:	29.0–97.0	30.0–95.0	82.0–92.0	16.0–98.0	31.0–96.0	
Embryos died in eggs	Mean:	5.7	4.3	3.4	2.1	3.0	3.8
	Range:	0.0–43.0	0.0–17.0	4.0–6.0	0.0–11.0	0.0–9.0	
No apparent development (sterile)	Mean:	26.3	20.8	9.7	14.5	25.5	20.7
	Range:	2.0–70.0	4.0–69.0	2.0–16.0	1.0–78.0	3.0–57.0	
Eggs destroyed by *Uniola* roots	Mean:					5.3	1.0
	Range:	None	None	None	None	0.0–42.0	
Young died in pipped eggs	Mean:	0.5	0.9		0.6	0.2	0.5
	Range:	0.0–2.0	0.0–4.0	None	0.0–2.0	0.0–2.0	
Young died in nest	Mean:	0.6	0.7	0.2	0.4	0.7	0.6
	Range:	0.0–2.0	0.0–3.0	0.0–1.0	0.0–3.0	0.0–3.0	
Total nests		13	19	4	14	12	62

shell successfully but were caught in the nest and died. This was caused by their inability to climb through the tightly packed deposit of hatched eggs or matted vegetation roots, or their tendency to burrow horizontally into hard sand instead of perpendicularly to the surface. In summing up the data this table presents, it may be said that those nests located at the base of dunes and rarely if ever covered by water are better situated than those on exposed beaches, especially those occasionally covered by tides, or on the vegetated dunes. As noted earlier in this paper, the female loggerheads selected sites at the base of dunes much more than in the other types.

The Hatchling

Size of the Young

A total of 398 young loggerheads from 31 nests were measured just after hatching. The carapace length ranged from 38 to 50 mm., with a mean of 45 mm.; the carapace width ranged from 31 mm. to 40 mm., with a mean of 35.5 mm.

The average weight of a newly hatched turtle, as determined from 104 specimens of one nest, is 21.2 grams. [These turtles are heavier than those reported by Caldwell, Carr, and Hellier (1956) from two localities in Florida—D.K.C.]

It was mentioned earlier in this paper that the larger turtles laid the smaller eggs, but whether a relationship exists between the size of the adult and young is not known.

Color of the Young

Newly hatched loggerheads have a wide range of color. The carapace varies from a yellowish buff through all shades of brown to a gray black. This coloration is by no means uniform, but lighter on the outer plates of the carapace. The plastron ranges from a pure creamy white to a gray black mottled with this white. Prominent points on the plastron are lighter than the grooved or flat areas. A light plastron is not necessarily correlated with a light carapace. Sometimes the individuals from a single nest have plastrons predominantly light or dark. These colors refer to those of wet specimens, for most dry specimens have a grayish cast.

Shield Variations

We examined 154 specimens from Cape Romain nests for variation in the number of costal shields [lateral laminae—D.K.C.], infra-

narginals, extra anals, and extra gulars—one pair of each of the latter wo is the expected number. The results of this analysis are included s Table 6. Although not evident from the table, the young of some ests tended to have greater shield variation than those of others.

TABLE 6

HIELD VARIATION IN YOUNG ATLANTIC LOGGERHEAD SEA TURTLES. DATA ARE ASED ON 154 NEWLY HATCHED SPECIMENS FROM CAPE ROMAIN, SOUTH CAROLINA N 1939. ALL COUNTS ARE MADE VIEWING THE TURTLE FROM THE DORSAL ASPECT.

ight	Left	Number of Turtles	Percent of Total
		Lateral laminae	
5	5	144	93.4
5	6	7	4.5
5	4	1	0.7
6	5	1	0.7
4	4	1	0.7
		Inframarginals	
3	3	57	37.0
4	3	14	9.1
3	4	21	13.6
4	4	56	36.3
5	4	2	1.3
6	4	1	0.7
4	5	1	0.7
5	5	2	1.3
		Extra (more than one pair) anals	
None		134	87.0
Median		13	8.4
Right & Left		5	3.3
Right, Left & Median		2	1.3
		Extra (more than one pair) gulars	
None		93	60.3
Median		60	39.0
Right & Left		1	0.7

Abnormal Young

During this investigation a few specimens were found which ight be termed freaks. One turtle that hatched and was otherwise

normal had no external openings for the eyes. Another had no left front flipper. One pair of embryos was found attached to the same egg yolk, and although completely developed, the turtles were dead. In another instance an embryo having one head joined to two bodies also died before hatching. An unusually small turtle that hatched and was otherwise normal had a carapace measuring only 34 mm. by 25 mm. (expected measurements are 45 mm. by 35 mm.).

The most interesting abnormality, however, was the presence of white embryos in about 15 percent of 65 nests examined. Never more than 3 or 4 were found in one nest. These embryos, in all stages of development, ranged from blueish white in the younger forms to creamy white in the fully developed ones. The carapace, plastron, and skin of the animals were uniformly colored. None of these abnormal embryos hatched, but some were found fully developed and alive in the egg a week or more after the normal turtles of the nest had hatched. One was found that had pipped the egg and then died. This probably indicates that development of the white embryos requires a longer period than normal ones. In addition, this absence of color appeared to be linked with the presence of malformations of the jaws and eyes.

Enemies and Mortality

Enemies of Adults

Enemies of the loggerhead are numerous. Formerly many of the adults were slaughtered for food in this region, although the practice is now outlawed by South Carolina. Some references indicate that sharks also destroy the adults. We have a local record of dogs killing loggerheads. According to a note in the Charleston Museum files, T. B. Fitzsimmons found two dead turtles with torn necks on the Botany Bay Beach, Edisto Island, within a few days of each other in the summer of 1929. A few nights later he saw his two hound dogs rush down to the beach and attack an adult turtle. He stopped the dogs and found the same wounds as on the other two turtles.

Enemies of the Young

The young are subject to tremendous predation by fishes, sharks, sand crabs (*Ocypode albicans*), raccoons, gulls, and to a lesser extent by crows. Sand crabs, which cover the beaches at night, form a gauntlet that the hatchling turtles must run, and many of the defenseless loggerheads never reach the sea. While the larger crabs

TABLE 7

FATE OF 343 NESTS OF THE ATLANTIC LOGGERHEAD SEA TURTLE CAPE ISLAND, SOUTH CAROLINA IN 1939. FIGURES REFER TO PERCENTAGE OF TOTAL NESTS PER BEACH TYPE.

	Truncate Dunes	Ledge	Wide Sloping Beach	Narrow Beach	Wide Beach	Barren	Total Nests	Average Percent
Hatched Successfully	None	27.5	27.2	67.2	49.1	63.8	151	44.0
Entered by crabs	10.0	35.0	60.9	29.0	35.6	30.4	140	40.8
Destroyed by raccoons	None	5.0	10.9	None	5.1	2.9	19	5.6
Washed away	90.0	32.5	1.0	3.8	10.2	2.9	33	9.6
Total number of nests	10	40	110	55	59	69	343	100.0
One nest per	197 feet	56 feet	28 feet	40 feet	78 feet	204 feet	82 feet	——

can easily carry the young turtles to their burrows and consume them, medium-sized crabs often have difficulty holding the struggling prey.

On 14 September 1931 according to a note in the Charleston Museum files, a young loggerhead was taken from the stomach of a "black-fish" (*Centropristes striatus*) and identified by E. B. Chamberlain. This fish was taken in 14 fathoms on "South Ground" off the Charleston bar. Interesting not only in its connection with predation, this also points to a possible migration of the newly hatched turtles to deep water. [See Caldwell, Carr, and Ogren (1959, herein)—D.K.C.]

Enemies of Eggs

Depredation of nests is very high in all parts of the loggerhead's range. McAtee (1934) says that nests of the loggerhead are pilfered by various enemies, but that the work of natural enemies is insignificant compared to the depredations of hogs, where they are present, and of man. At Cape Romain neither of these two predators is present, but depredations by sand crabs and raccoons are extensive. Table 7 presents the fate of 343 Cape Island nests. The data are tabulated for beach types and for the entire island. Only 44 percent of the nests hatched without being disturbed. Sand crabs entered 40.8 percent, although this does not mean that some of these nests did not later hatch some young.

Sand Crab. Crabs entered nests regardless of the stage of incubation and condition of the nest site. It is remarkable how these predators can locate an egg deposit after all surface signs of the nest have been obliterated. It may be largely accidental, or connected in some manner with the presence of the soft sand immediately over the eggs. Newly made nests still marked by the turtle's crawl are easily found by the crabs, which dig shallow 3- to 12-inch holes experimentally all over the site. This sometimes results in their finding the egg deposit. A nest that has been entered usually shows a hole surrounded by scattered egg shells. In soft sand this entrance hole may be gradually excavated to reach 1 foot in diameter instead of the customary 3 or 4 inches. The crabs, sometimes a dozen in the same nest, may either eat the eggs in the nest or remove them to nearby dunes or to their permanent burrows. Although only one crab may discover an egg deposit, sometimes a dozen more may move into the area within the space of a week and dig their burrows around the original one. The number of sand crabs on the Cape Island beach was large, and appeared to be greatest on those types of beach having the most nests. Whether this was due to the abundance of nests

or to more favorable environment for the crabs is not known. The wide sloping beach that had the most nests (1 every 28 feet) also had the greatest amount of crab predation, 60.9 percent of the 110 nests made on that type.

Raccoon. Raccoons destroyed 5.6 percent of the total number of nests. Predation by this animal was decidedly higher in previous years, and the decline is attributed to control measures during the winter months. A wide variety of foods on wooded Bull's Island makes raccoon depredation of turtle nests there low. On Cape Island with its limited flora and fauna, raccoons must depend for their food on fiddler crabs, oysters, insects, mice, bird eggs, and turtle eggs. Twenty-four raccoon droppings collected throughout June, July, and August from Cape Island contained remains of fiddler crabs (100 percent) with a trace of insect matter (*Coleoptera*). In fact, fiddler crabs are the major year-round raccoon food on Cape Island. With such a limited diet, it is little wonder that raccoons relish loggerhead eggs.

On Cape Island raccoons patrolled the beach and dunes singly or in family groups of two or three. It is our belief that nest depredation was carried on by relatively few individuals who covered the same area throughout the summer. The behavior of these animals around nests was irregular. Many times they walked directly over egg deposits the night they were laid, not even pausing to investigate. Freshly made nests with crab burrows down to the eggs and shells scattered on the surface would also fail to arouse the curiosity of passing raccoons. Other nests were raided the night they were made or even many days after incubation had started and the site had been obliterated. The entire clutch of fresh eggs was usually eaten after they had been reached through a large excavation, and the shells scattered on the surface. Sometimes a few dozen eggs were left intact in the bottom of the nest. Eggs that contained developing young were broken and scattered rather than eaten, and especially when the embryos were almost ready to emerge. Young loggerheads are doubtlessly caught and eaten by raccoons. Around one nest that had hatched the preceding night we found six young turtles with their heads missing; tracks indicated this was raccoon work.

Erosion. Another agency of nest destruction on Cape Island was erosion by the action of the surf. The periods of greatest loss occurred whenever the highest monthly tides were accompanied by a strong wind. Nests uncovered by the pounding of the surf were immediately entered by sand crabs. As shown in Table 7, most wash-

ing (90 percent) occurred on the low beach below the truncate dunes, a type that was chosen least by nesting turtles. On the other hand, the least damage (1 percent) was on the wide sloping beach, the type most used by the female loggerheads; this stretch of beach is much higher than the former.

Invertebrate Life in the Nest

Nests opened by predators soon develop a population of flies and beetles, attracted for feeding and egg-laying. Such concentrations attract birds; turnstones and sanderlings have been observed feeding around the opened nests. Small nematodes commonly develop on broken eggs. Mites collected from the plastron sutures of a hatchling loggerhead were identified as *Macrocheles* sp. (Parasitidae) by Dr. Ewing of the U. S. National Museum, who stated that the group is not parasitic and doubted "its specific association with the turtle."

Literature Cited

Babcock, Harold L.
1937. The sea turtles of the Bermuda Islands with a survey of the present state of the turtle fishing industry. Proc. Zool. Soc. London, series A, vol. 107, pt. 4, pp. 595-601.

Caldwell, David K., Archie Carr, and Thomas R. Hellier, Jr.
1956. Natural history notes on the Atlantic loggerhead turtle, *Caretta caretta caretta*. Quart. Jour. Florida Acad. Sci., vol. 18, no. 4, pp. 292-302, 2 figs.

Carr, Archie, and David K. Caldwell
1956. The ecology and migrations of sea turtles, 1. Results of field work in Florida, 1955. Amer. Mus. Novitates, no. 1793, 23 pp., 4 figs.

Coast and Geodetic Survey, U. S. Department of Commerce
1939. Tide tables—Atlantic Ocean, for the year 1939. Washington: Serial no. 604, 313 pp.

Coker, R. E.
1906. The cultivation of the diamond-back terrapin. North Carolina Geological Survey, Bulletin 14, 69 pp.

McAtee, W. L.
1934. The loggerhead. Nature Magazine, for January, 1934, pp. 21-22.

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NOTES ON THE CROWN CONCH, MELONGENA CORONA

By DAVID K. CALDWELL
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Studies were begun in late November, 1954, to determine the rate of growth of the crown conch, *Melongena corona* (Gmelin), at Cedar Key, Levy County, Florida. Gunter and Menzel (1957) noted that there is disagreement as to the use of subspecific names for this species of mollusk but following Clench and Turner (1956) the Cedar Key population would be identified as *M. c. corona* (Gmelin).

The growth study was first attempted by the method outlined by Lenderking (1952) for a study on *Littorina angulifera* (Lam.) in south Florida. This consists of notching the lip of the shell with a triangular file, returning the mollusk to the oyster bar, and on recovering it later and noting the growth on the lip beyond the notch, calculating back to determine its original size (height)—thus by simple subtraction determining the increase in height of the shell. Although a number of the Cedar Key *Melongena* were recovered, and a number of the notches were filling in, leaving an obvious scar, only 3 of the smaller individuals showed any lip growth so that when circumstances forced the discontinuance of the project in late October, 1955, this phase of the growth study was abandoned.

Two large samples were collected, on May 29 and October 22, 1955, and measured in an effort to study growth by comparing modes of length-frequency curves. This method was also discontinued as the modes for the two samples were so similar that no growth could be ascertained. The individuals sampled during the study ranged from 42 to 110 mm. in greatest height of the shell. There was a single mode at approximately 75 mm. in each sample. Hathaway (1957) found that only the larger individuals of *Melongena* occurred on the oyster bars (where my entire study was conducted). Since I also found only large individuals, the failure of both growth studies may have been due to my dealing with only adult or sub-adult individuals at, or nearing, their maximum size and exhibiting at most very slow growth. Although no significant findings were made on rate of growth, the conchs collected in November, December, and January had hard lips, while many of the smaller conchs collected in the late spring

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(April and May) had very soft lips, indicating, as would be expected, that growth occurred during the warm months.

Despite the failure to establish growth rates, a number of natural history notes were obtained that seem worthy of presentation here. The most significant of these relate to the year-round presence and the movements of these animals.

Although the markings were such that individuals could not be recognized (unless they were recaptured and subsequently released again), each sample had the lips of the shells notched in a different position so that an individual could be recognized as having been marked and released with a given sample.

On November 27, 1954, 30 specimens were captured, marked by notching the middle of the lip, and released at one spot (about 2 feet in diameter) on a small intertidal oyster bar near the shore at the end of the airstrip on Way Key, Cedar Keys. On December 3, 1954, 49 more were similarly captured, marked, and released at the same point. The dates were so close, and the bar on which they were collected so small, that these two samples were considered as one.

On January 8, 1955, 107 individuals were marked by notching the upper part of the lip and were released in the same spot as those of the first sample. Again, all had been captured on this same bar.

On April 17, 1955, 307 mollusks were marked by notching the lower part of the lip. In this instance, the individuals were collected on the original bar and on a smaller bar between it and the shore. All were released at the same spot as the other samples.

Collections were made on May 29 and October 22 in an effort to recover individuals showing growth, but no further marking was done.

Each of the collections subsequent to the original marking on November 27 yielded marked individuals. The following is a summary of these recaptures.

In this summary, the date or dates of release are given first, followed by the date of recapture, the number of days at liberty, and the minimum distance traveled:

XI-27-54 to XII-3-54, 7 days, 20^{1} feet; XI-27-54 and XII-3-54 to I-8-55, 29 or 36 days, 3, 5, 6, 7, 8^{2}, 15, 21^{1}, and 66 feet; XI-27-54 and XII-3-54 to IV-17-55, 128 or 135 days, 22, 26, 29^{2}, 43, 97, 105,

132, and 139 feet; I-8-55 to IV-17-55, 99 days, 2, 3, 4, 4, 8, 13, 16, 22, 33, 42, 42, 43, 65, 128, 143, and 157 feet; XI-27-54 and XII-3-54 to V-29-55, 170 or 177 days, 6, 13, 16, 19, 21, 24, 26, 29, 31, 32, 33, 51, 88, 98, 98, and 142 feet; I-8-55 to V-29-55, 141 days, 20, 26, 27, 29, 31, 36, 50, 70, 119, and 141 feet; IV-17-55 to V-29-55, 46 days, 1, 3, 4, 26, 34, 48, 50, 62, 64, 71, 75, 96, 138, 139, and 161 feet; XI-29-54 and XII-3-54 to X-22-55, 316 or 323 days, 1, 7, 45, 75, 98, 105, 131 and 249 feet; I-8-55 to X-22-55, 289 days, 3, 96, 99, 102, 108, 112, and 231 feet; IV-17-55 to X-22-55, 194 days, 3, 37, 85, and 237 feet.

While the paths could not be ascertained, they probably followed as close to the oyster bars as possible, since few individuals were found off the bars, and these were in close proximity to the oysters. The bar on which the conchs were released was approximately an oval about 100 by 40 feet and located about 50 feet from shore. There were no other bars for several hundred feet in one direction along-shore or offshore, but there were a number of bars in the opposite direction along the shore. The release bar was thus the last of a series of small along-shore bars, just off the shore. The pattern of bars was not in a straight line, parallel to the shore, but rather the bars were quite irregularly placed, actually touching the shore in some places. The distances between bars were 10 feet or less, so that the conchs would not have to travel long distances over open sand (submerged or not—depending on the tide stage) in getting from bar to bar. In this regard, I rarely obtained a specimen of *Melongena* in some 25 trawling collecting trips to deep and shallow flats, in channels, and on channel edges (all these stations away from oyster bars) made in connection with a fish study at Cedar Key conducted from February, 1953, through April, 1954 (for a detailed description of these habitats, see Caldwell, 1957).

The distances traveled, as given in the above summary, are straight lines, determined by pacing in a direct course between the points of capture and release. They are minimal, as the animals may have meandered considerably as well as traveled curved routes. The longer distances necessarily are over routes which include one or more oyster bars in addition to the original release bar. Oyster bars more than 250 feet from the original

[1] Same individual recaptured twice; movement in diametrically opposite directions.

[2] Same individual recaptured twice; movement in diametrically opposite directions.

point of release were not visited, and probably some snails had moved even futher than indicated in the summary. The most distant bars were visited only late in the study, and hence longer distances could have been traversed by the mollusks earlier in the study, and they would not have been recorded.

Evidently from the data presented in the summary, movement is random, and there is no apparent relationship between time and distance traveled. Although no records of size were kept, there appeared to be no correlation between the size of the individuals and the distance traveled, although the larger individuals were found lower on the bar. Nor was there any tendency to stay together in groups; that is, two individuals at liberty 10 days and moving 10 feet were not necessarily together at the end of the period, since, though some *were* near to one another, the 10 feet moved was just as often in opposite directions from the release point. That some individuals were only a few feet away from the release point after nearly a year may mean that they had not moved, but more likely they had moved away and in their random movements over the bar were, by chance, back on that part of the bar when recaptured—perhaps having moved back and forth over the point (and far beyond) a number of times during the year.

As each marked individual was recaptured, it was marked a second time by code-notching the bases of the prominent spines of the shell. The fact that only two individuals so marked were recaptured a second time, and none more than twice, indicates that there must be considerable movement away from the bars and out of the collection zone. Conversely, the large number of unmarked snails collected at each sampling indicates either a great influx of individuals to those bars under study, or excellent camouflage. While camouflage is almost certainly a factor in accounting for so many unmarked snails, so much effort was expended in trying to find all snails that immigration, as corroborated by the marking results, seems the more tenable. Dead shells were always examined for marks, but none of those collected had been notched. Actually, relatively few such shells were seen and the primary predators on the crown conchs at Cedar Key may employ methods which either crush the shell so badly that it would not have been examined or carry the snail

away from the bar to be consumed.

No egg cases were seen, but copulating pairs, with the male considerably smaller in each case, were observed on the oyster bars in April and May.

Gunter and Menzel (1957:85) noted that on some reefs north of Cedar Key in the Gulf of Mexico (in Apalachicola Bay) *Melongena* were absent in winter, where they had been in the fall. From my findings at Cedar Key, more probably the crown conchs, although capable of movement, were buried, or partially buried, in the mud on or adjacent to the reefs, and because of excellent camouflage were not readily seen. At Cedar Key an effort was made to collect for marking every living *Melongena.* Some were taken at every collection: 30 on November 27, 50 on December 3, 1115 on January 8, 331 on April 17, 269 on May 29, and 238 on October 22. Since about the same collecting effort was expended each time, or actually even less in summer because the mollusks were easier to find, a trend is thus indicated toward scarcity in winter and abundance in summer on the oyster bars, but never complete absence. The increased number collected in the winter month of January was probably due to an immediately previous, extended warm period of about 3 weeks, and lends further evidence to the continuous presence of the conchs on the bar and the conclusion that they bury in cold weather.

Gunter and Menzel (1957) and Menzel and Nichy (1958) have discussed *Melongena corona* in relation to its predation on oysters. While I found a few crown conchs feeding on oysters, feeding was so occasional in relation to the number of conchs found that this predator probably is not a major one, as noted by these writers, except, as pointed out by Clench and Turner (1956:161), where by sheer numbers it may be a menace.

Acknowledgements: For helpful comments and criticisms regarding the completed manuscript, I wish to thank William W. Anderson, Frederick H. Berry, and Jack W. Gehringer, all of the United States Fish and Wildlife Service at Brunswick, Georgia; and Philip A. Butler of that Service at Pensacola, Florida. My thanks go also to William J. Clench, of the Museum of Comparative Zoölogy at Harvard University. He was generous in encouraging the early part of the study and in critically reading the final manuscript. Dale W. Rice, then of the University

of Florida, kindly aided me in the field during the early phases of the project.

Literature Cited

Caldwell, David K. 1957. The biology and systematics of the pinfish, *Lagodon rhomboides* (Linnaeus). Bull. Florida State Mus., Biol. Sci., *2* (6) : 77-173.

Clench, William J., and Ruth D. Turner. 1956. The family Melongenidae in the western Atlantic. Johnsonia, *3* (35) : 161-188.

Gunter, Gordon, and R. Winston Menzel. 1957. The crown conch, *Melongena corona,* as a predator upon the Virginia oyster. Nautilus, *70* (3): 84-87.

Hathaway, R. R. 1957. The crown conch, *Melongena corona* Gmelin, and the oyster, *Crassostrea virginica* Gmelin. Proc. Natl. Shellfish Assoc., *48:* in press. (not seen, citation *fide* Menzel and Nichy, 1958).

Lenderking, Ruth E. 1952. Observations on *Littorina angulifera* Lam. from Biscayne Key, Florida. Quart. Journ. Florida Acad. Sci., *14* (4) : 247-250.

Menzel, R. Winston, and Fred E. Nichy. 1958. Studies of the distribution and feeding habits of some oyster predators in Alligator Harbor, Florida. Bull. Mar. Sci. Gulf and Caribbean, *8* (2) : 125-145.

)FFSHORE OCCURRENCE OF LARVAL
VER MULLET, *MUGIL CUREMA*, IN
E WESTERN GULF OF MEXICO.—Much
been written in recent years concerning the
e of spawning of the American mullets of
genus *Mugil*. Evidence presented by Broad-
1 (*Florida State Bd. Conserv., Tech. Ser. 7:21,*
3), Arnold and Thompson (*Copeia 1958(2):*
, and Anderson (*U. S. Fish and Wildlife*
., *Fish. Bull. no. 144,* 1959) indicates that the
)ed mullet, *Mugil cephalus* Linnaeus, spawns
hore. Anderson (*U. S. Fish and Wildlife*
., *Fish. Bull. no. 119,* 1957) summarized
lished data and presented new records which
ved that the silver mullet, *Mugil curema*
nciennes, spawned offshore in the Atlantic,
he had no records for such an occurrence in
Gulf of Mexico. Hollister (*Zoologica 22(17):*
1937) also found larval silver mullet (6–12
.) offshore over deep water, presumably off
muda. Various workers (Gunter, *Publ. Inst.*
. *Sci., Univ. Texas, 1(1):52,* 1945—Texas;
)y, *Tulane Stud. Zool. 2(8):214,* 1955—middle
f coast of Florida; Joseph and Yerger, *Florida*
e Univ. Stud. no. 22, Pap. Oceanogr. Inst. no.
2, 1956—northern Gulf coast of Florida) all
e that the smallest silver mullet they col-
ed inshore in the Gulf of Mexico were 23–24
. in standard length. This fact alone is good
lence for an offshore spawning by silver mul-
as discussed by Anderson (*op. cit.*) in noting
lar Atlantic size records inshore. Further
ion to conclude an offshore spawning for
species in the Gulf as well as the Atlantic
videnced by the first known series of offshore-
ght larval (as defined by Anderson, *op. cit.*)
er mullet from that area—which we report
his paper. In addition, they are the smallest
)rted from the Gulf of Mexico.

)n May 25, 1954, at U. S. Fish and Wildlife
ice M/V *Oregon* station 1074, Caldwell dip-
ed a tiny school (only about 4 inches in di-
ameter) of silver mullet as the fishes swam at

the surface near the drifting vessel. Station 1074 was located at latitude 24°00'N., and longitude 96°50'W., over 575 fathoms, some 55 miles from the nearest land. The air temperature was 78° F., the surface water temperature 77° F. The fish were collected at dusk. Fourteen of the specimens (7.2 to 9.8 mm. Standard Length) were deposited in the University of Florida Collections (UF 3913).

These specimens are of interest not only because they shed further light on the problem of the early life history of *Mugil curema,* but also because they more clearly define the sizes at which certain ontogenetic changes take place. Our fully-scaled 7.2-mm. specimen differs from the largest larval individual (7.0 mm.) described by Anderson, in that it has all of the fins and their rays fully developed and has a shallowly concave caudal fin, though the lobes remain well rounded. The shapes of the other fins also are more like juvenile silver mullet than those of Anderson's 7.0-mm. fish. The single nostril slit of our 7.2-mm. specimen has begun to pinch in midway along its length, and the double nostril of the juvenile has been fully accomplished in our 9.8-mm. individual. The preorbital bone is just beginning to appear in our 9.8-mm. specimen, though it has no serrations. Other characters of our specimens in general are more like Anderson's 14.5-mm. specimen than his 7.0-mm. fish.

Caldwell wishes to thank Stewart Springer for allowing him to participate in the cruise as an observer, then from the University of Florida, and we are grateful to Frederick H. Berry and Jack W. Gehringer for comments regarding this manuscript.—David K. Caldwell and William W. Anderson, *U. S. Fish and Wildlife Service, Brunswick, Georgia.*

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pp. 454–455

SURF-RIDING BY ATLANTIC BOTTLE-NOSED DOLPHINS

Caldwell (Jour. Mamm., 37: 454–455, 1956) has summarized data which clearly document the phenomenon that captive Atlantic bottle-nosed dolphins, *Tursiops truncatus* Montague, will play with objects with which they come in contact. Brown and Norris (*Ibid.*, 37: 317, 1956) cited similar behavior for captive Pacific white-sided dolphins, *Lagenorhynchus obliquidens* Gill. From personal observations (Caldwell), and those of others with whom we have talked, this behavior is also exhibited in nature. Gunter (Copeia, 1953: 188–190) has summarized a number of instances of similar play with floating objects exhibited by various species of fish. The "natural curiosity"—in a broad sense, play—of porpoises for floating objects may account, under fortuitous circumstances, for the reports of these mammals coming to the aid of drowning humans (Siebenaler and Caldwell, Jour. Mamm., 37: 127, 1956).

Mariners in all oceans are familiar with the act exhibited by many delphinids of swimming at the ship's bow when it is under way, and often the dolphins are seen to leap entirely out of the water. Apparently having no other significance, these acts may also be interpreted as play. Another example of similar play in nature, in which no foreign objects were involved, is that recorded below; this may, for lack of a more erudite and less descriptive term, be called "surf-riding." We made the two observations independently, and it was not until the Florida incident was prepared for publication that the North Carolina one was recalled.

The coastline in front of Florida's Gulfarium, at Fort Walton Beach on the Gulf of Mexico coast, consists of the sand beach, an adjacent deep slough, and a shallow submerged sand bar about 100 feet off the beach, all parallel. On March 10, 1955, while standing on the third-floor upper deck of the Gulfarium, Caldwell observed, with the aid of 6 × 30 binoculars from a distance of about 250 yards, about 15 Atlantic bottle-nosed dolphins as they leisurely made their way eastward along the coast. The porpoises were obviously surf-riding on the large rollers which were breaking, parallel to the beach, over the bar into the slough. The animals rode the top front of the wave with their heads down and only their dorsal fins and a small part of their backs exposed. The long axis of the body was oriented at right angles to the beach. The water was quite clear and the weather sunny, so that with the advantage of observation from a height it was certain that each porpoise made several "rides" before the school moved out of sight. After each ride the individual swam along the slough for a short way and then turned seaward over and beyond the bar to come in on another roller.

A similar observation was made (by Fields) at Fort Macon State Park, North Carolina, in the summer of 1950. The bottom was relatively smooth in this instance, with no bar or other breaks in contour. About 12 *T. truncatus* were observed swimming westward, parallel to the beach, just seaward of a roped-off public swimming area. After reaching a point slightly beyond this area, the school milled around and soon began to surf-ride singly or in groups of two to four. In the latter case the animals rode the same wave, with their bodies nearly parallel. Each porpoise began swimming beneath the surface of an incoming swell and, as the wave crested and began to break, the animal shot forward until it was riding the forward slope of the wave. Most of the porpoise's head (held down) and much of its back was out of the water—unlike the Florida porpoises. After the wave was "caught," the porpoise was observed to ride it with much the same ease and in the same manner as a human surf-rider. After riding the wave to a point where the water was only about 3½ feet deep, the porpoise stopped and returned to the rest of the school, which was still milling just beyond the breakers. The activities of individual porpoises were not observed, and it was not known whether all animals were taking part in the activity, which continued for about 15 minutes. At the end of this period, the school continued on westward and no additional surf-riding was observed.

It is interesting to note that in both instances people were on the beach and were swim-

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ming in the surf in close proximity to the surf-riding porpoises. Apparently in no case was this human activity disturbing to the porpoises.

We wish to thank William W. Anderson, Frederick H. Berry and Jack W. Gehringer, of the U.S. Fish and Wildlife Service, and James N. Layne, of the University of Florida, for helpful suggestions regarding the manuscript.—David K. Caldwell and Hugh M. Fields, *U.S. Fish and Wildlife Service, Brunswick, Georgia.* *Received April 26, 1958.*

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Systematic and Ecological Notes on Some Fishes Collected in the Vicinity of Tortuguero, Caribbean Coast of Costa Rica

by

David K. Caldwell *, Larry H. Ogren**, and Leonard Giovannoli***

(Received for publication December 2, 1958.)

The fishes listed in this report represent collections made primarily by Ogren and Giovannoli while they were in Costa Rica during the summers of 1956-58 and 1955, respectively, as University of Florida Research Assistants engaged in a study of the ecology and migrations of sea turtles (National Science Foundation Grants G-1684 and G-5479, University of Florida-Principal Investigator, Archie Carr). A few additional specimens, designated in the following annotated list, were taken by others who were at Tortuguero during the months Ogren and Giovannoli were collecting.

Since the specimens were taken during only one season of the year, with limited equipment, and only incidental to the turtle work, this list is not intended as a presentation of the entire fish fauna of the area. However, the locality is isolated, and knowledge of some of the fish species augments what is known of the ecology and ranges of fishes known to occur in neighboring or distant countries to the north or south. This is particularly true of the marine species, as practically nothing has been written concerning their actual occurrence in Caribbean Costa Rican waters.

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** Research Assistant, University of Florida.

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Contribution No. 35
U. S. Fish & Wildlife Service

Tortuguero is a small sawmill and turtle-fishing village approximately 52 miles northwest of Puerto Limón and 17 miles southeast of Barra del Colorado, on the Caribbean coast of Costa Rica, Central America (CARR and GIOVANNOLI, 10).

The village is on a barrier island separated from the mainland by a brackish lagoon (Figure 1). Rio Tortuguero and Agua Fria are the primary sources of fresh water feeding the lagoon in the vicinity of Tortuguero, though creeks of varying sizes also enter it near the village. A water hyacinth—and log—filled creek (Caño Palma) connects this lagoon with the neighboring Simon lagoon to the north, but the obstructions are so dense that there is no navigable inside water passage to Tortuguero from that direction. Tortuguero lagoon is choked with hyacinths to the south of its confluence with the Tortuguero River, and only during heavy rains when there is considerable water in the lagoon can an occasional motor launch push its way through the five miles of water hyacinths and establish inside water passage with the village of Parismina. Río Tortuguero is one of many rivers draining the highland of Caribbean Costa Rica, but is not directly connected by fresh water with the large Nicaraguan lakes, as shown on some maps. However, the coastal fresh and brackish-water fish fauna of the Tortuguero area has a vague connection (especially during times of flood) with these lakes via the brackish creeks and lagoons connecting the Tortuguero lagoon, via Simon lagoon, with the Río San Juan—draining lake Nicaragua and entering the sea at Barra del Colorado.

Unless otherwise noted, the identifications and systematic notes were made by Caldwell, and the specimens are deposited in the University of Florida Collections (UF). A few specimens are deposited in the collections of the Academy of Natural Sciences of Philadelphia (ANSP).

Lengths are standard length, unless otherwise stated, in millimeters, and were taken with a ruler and dividers. The points of the dividers were placed at the tip of the snout and at the base of the mid-caudal rays.

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Aside from the indirect support from the National Science Foundation, we wish especially to thank Teodoro Quirós C. of the Atlantic Trading Company at Tortuguero and Leo Martínez of that village for their consistent cooperation in furthering the collecting. Kay Eoff, of the University of Florida, aided Ogren in collecting in the summer of 1958. William W. Anderson, Frederick H. Berry, and Jack W. Gehringer, of the United States Fish and Wildlife Service at Brunswick, Georgia; Archie Carr, of the University of Florida; Robert R. Miller, of the University of Michigan; and Loren P. Woods, of the Chicago Natural History Museum, were all generous in making comments and suggestions regarding the manuscript.

COLLECTING STATIONS

Although the fishes were collected within a short distance of the village

of Tortuguero, three major habitats (marine, brackish, and freshwater) are represented. The following variously-detailed ecological notes were made by Ogren and Giovannoli, and it should be emphasized that the data are based on those conditions which existed at the time of the specific collections. Due to great seasonal and annual variation in rainfall, which so markedly affect the volume of water coming down the rivers, some of the brackish stations might be quite saline during a dry spell and freshwater stations may prove brackish. Conversely, saline stations might on occasion be quite fresh. Mileages are water miles. Station numbers refer to Figure 1. Species numbers refer to the annotated list in this paper.

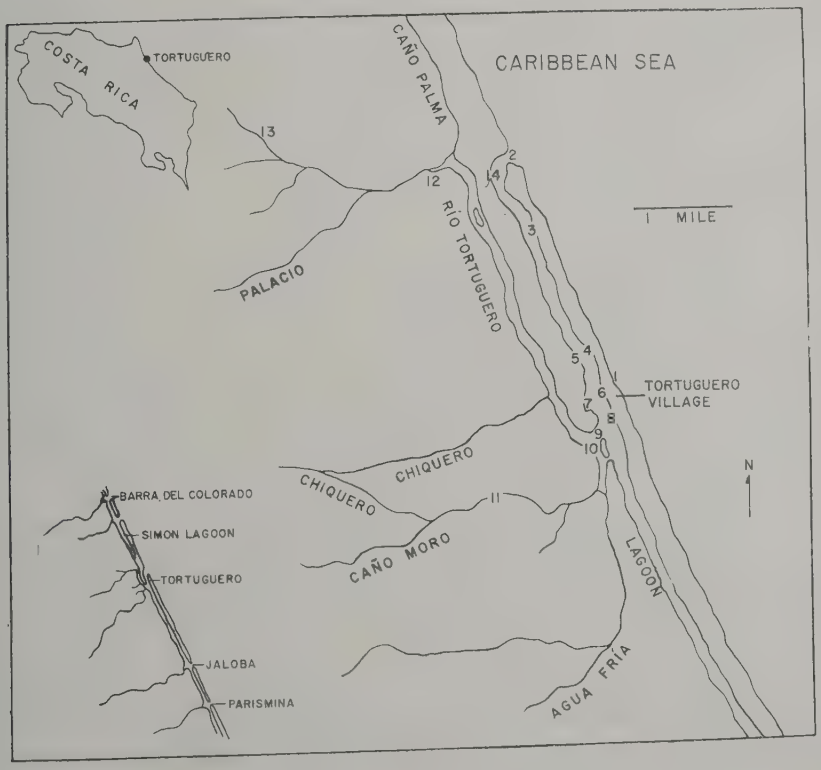

Fig. 1: Map showing Tortuguero and its relationship to other localities in Caribbean Costa Rica. Numerals refer to collecting stations described in the text. The village is located at latitude 10° 34' N., longitude 83° 32' W.

Station 1. Open beach near the village of Tortuguero. The beach is black volcanic sand, and slopes sharply into rather deep water. A heavy surf was almost always present.

Station 1A. August 14, 1955. Giovannoli. Fishes literally driven onto the beach in their frantic efforts to evade capture by larger predatory fishes. This is apparently a frequent phenomenon, as the children of the village seem to expect it and eagerly gather the small fishes.

Species: 2, 3, 4, 5, 21, 24.

Station 1B. July 15, 1956. Ogren. Fish found dead on beach.

Species: 37.

Station 1C. July 30. 1958. Ogren field number 451. Fish scooped as it buried in the sand at the surf line as a wave retreated.

Species: 45.

Station 2. Just inside the inlet, where the Tortuguero lagoon enters the sea.

Station 2A. August 26, 1955. Giovannoli and Carr. The river, swollen by rains at the time of collection, flowed with such volume into the lagoon that it was only slightly saline nearly to the inlet, even at high tide. Shark with remora attached taken with hook and line.

Species: 1, 54.

Station 2B. July 29, 1959. Ogren and Eoff. Ogren field number 449. *Caranx* and *Oligoplites* caught on jigs. *Echeneis* and shark caught on baited hooks.

Species: 1, 26, 27, 54.

Station 3 Tortuguero lagoon about ¾ mile from inlet. September 1, 1956. Ogren and Obid Martínez. Ogren field number 152. Time, 1300 - 1400 hours. Incoming tide, water brackish. Bank gently shelving to several feet from shore, then rapid drop-off. Depth at collecting point to four feet. Bottom sandy. Floating water hyacinths (*Eichornia*) only aquatic vegetation. Fish seined, water baited with bananas.

Species: 9, 11, 16, 22, 23, 25, 32, 33, 36, 41, 42, 47, 49, 53, 55.

Station 4. East bank of Tortuguero lagoon, about 2 miles from inlet. Bottom sandy muck. Depth about 3½ feet at shore, dropping off sharply to 20-25 feet. Water brackish, brown stained. Water hyacinths and grass (*Panicum*).

Station 4A: July 25, 1955. Giovannoli. Fish shaken from hyacinth roots.

Species: 55.

Station 4B. July 27, 1955. Giovannoli. Cichlids taken with hook and line. Eleotrids shaken from hyacinth roots.

Species: 40, 49.

Station 4C. September 3, 1956. Ogren. Ogren field number 157. Fish taken with cast net around submerged brush pile. Incoming tide. Water turbid.

Species: 8, 9, 11, 12, 52, 53.

Station 4D. September 9, 1956. Ogren. Ogren field number 175. Fish taken with a cast net around brush pile. Falling tide. Some water turbidity.

Species: 1, 9, 41, 43, 54.

Station 4E. July 28, 1957. Ogren. Ogren field number 233. Fish in association with hyacinths, seined.

Species: 31.

Station 4F. August 31 and September 1, 1957. Ogren. Ogren field number 277. Fish seined around hyacinths.

Species: 19, 46, 49.

Station 5. West bank of Tortuguero lagoon across from Station 4, about 2 miles from inlet, at the edge of a river swamp forest. July 28, 1956. Ogren. Ogren field number 48. Mid-afternoon. Bottom sand (flats). Depth 1-3½ feet, shallows extending well out from shore. No current. Submerged aquatic plants (*Potamogeton* and *Najas*) present. Water turbid with a slight brown stain. Fish seined near bank.

Species: 22, 36, 41; 42, 49, 51, 52, 53.

Station 6 East bank of Tortuguero lagoon, about 2½ miles from inlet, in back of the sawmill at a boatshed and landing. Depth ½-6 feet. Water brown and brackish. Bottom sandy. Some hyacinths near shore, no other aquatic plants.

Station 6A. August 22, 1955. Giovannoli. Fish associated with hyacinth roots.

Species: 11, 40, 41, 42, 44, 46, 47, 49, 51, 55.

Station 6B. July 13, 1956. Ogren. Ogren field number 1. Time, 2400 hours. Falling tide, slight current. Fish, swimming at surface, collected by dipping with a seine with the aid of a headlight.

Species: 22.

Station 6C. July 13, 1956. Ogren. Ogren field number 2. Time, 2400 hours. Falling tide, slight current. Fish, swimming near the bare bottom in an open area, seined.

Species: 36, 49.

Station 6D. July 13, 1956. Ogren. Ogren field number 3. Time, 2400 hours. Falling tide, slight current. Fish, near bank around hyacinth roots, seined.

Species: 11, 12, 40.

Station 6E. July 15, 1956. Ogren. Ogren field number 4. Time, 1500 hours. Fish taken by seine near shore in an area that was baited with dead crabs.

Species: 9, 11, 22, 41, 47, 53.

Station 6F. July 16, 1956. Ogren. Ogren field number 5. Time, 1000 hours. Fish taken as at Station 6E.

Species: 9, 11, 16, 28, 41, 47, 49, 53.

Station 6G. July 17, 1956. Ogren. Ogren field number 7. Fish collected during morning and afternoon. Specimens taken as at Station 6E.

Species: 41, 55.

Station 6H. July 24, 1956. Ogren. Ogren field number 25. Time, 1500 hours. Depth 3 feet. Fish seined near sandy shore.

Species: 9, 11, 12, 13, 41, 47, 49, 55.

Station 6I. August 25, 1956. Ogren. Ogren field number 131. Time, 2130-2200 hours. Low tide. Fish collected with a dipnet by the light of a headlight.

Species: 22.

Station 6J. August 28, 1956. Ogren. Ogren field number 141. Time, 2200 hours. Water low, depth 4 feet. Some muck associated with sandy bottom. Fish

collected with dip net.

Species: 22.

Station 6K. July 9, 1958. Ogren. Ogren field number 420. Collected by dipnetting at night.

Species: 22, 23.

Station 6L. July 16, 1958. Ogren. Ogren field number 430. Collected by dipnetting in shallow water near bank, among drifting hyacinths. Incoming tide.

Species: 11, 22, 29, 33, 34, 46.

Station 6M. July 17, 1958. Ogren. Ogren field number 431. Time, 1900-2100 hours. Dipnetted. High tide.

Species: 6, 11, 19, 22, 29, 31, 33, 35, 36.

Station 6N. July 18, 1958. Ogren. Ogren field number 434. Dipnetted at night.

Species: 6, 11, 19, 22, 29, 30, 33, 34, 36, 46, 47, 55.

Station 6P. July 24, 1958. Ogren. Ogren field numbers 441 and 442. Fish caught in trap baited with coconut meat.

Species: 48, 55.

Station 6Q. July 27, 1958. Ogren. Ogren field number 448. Fish caught in trap baited with coconut meat and shrimp.

Species: 30, 31, 41, 43, 49.

Station 6R. July 30, 1958. Ogren. Ogren field number 452. Fish caught in trap baited with coconut meat.

Species: 40.

Station 6S. August 2, 1958. Ogren. Ogren field number 455. Fish seined during the late evening.

Species: 9, 11, 16, 29, 33, 36, 40, 41, 42, 43, 47, 50.

Station 6T. August 30, 1958. Ogren. Time, 2000 hours. Dipnetted.

Species: 23.

Station 7. Tortuguero lagoon across from Station 6, about 2½ miles from inlet. Shallow flats extending about 25 yards out into the river. Depth 1-3 feet. Sand bottom. Aquatic vegetation: *Potamogeton, Najas, Utricularia,* and filamentous green algae.

Station 7A. July 24, 1957. Ogren. Ogren field number 225. Night. Fish at surface, collected by hitting with a machete and by hand-grabbing.

Species: 15.

Station 7B. July 11, 1958. Ogren. Ogren field numbers 422, 423, and 424. Time, 1930-2100 hours. Incoming tide. Fish dipnetted.

Species: 14, 15, 22.

Station 8. East bank of Tortuguero lagoon, about 2 ¾ miles from inlet. September 2, 1956. Ogren. Ogren field number 155. Bottom muck. Slight current, estimated 2-3 mph. Water high, depth 6 feet. Water highly turbid, with some brown stain. Large fish taken near shore with hook and line. Eleotrids shaken from hyacinth roots.

Species: 31, 40, 43, 46, 48.

Station 9. At point of land, to the north, where the Tortuguero river enters the lagoon, about 3 miles from inlet. July 12, 1957. Stephen Carr. Ogren field number 205. Afternoon. Silt bottom. Hyacinths, while floating, attached to and growing well out from bank, along with *Panicum* grass. Fish collected with hook and line from deep water alongside hyacinths, shrimp bait.

Species: 38, 39.

Station 10. Near confluence of the Tortuguero river, Caño Moro and other creeks, and lagoon. Silty bottom. Hyacinths as at Station 9.

Station 10A. July 13, 1957. Ogren. Ogren field number 208. Night. Fish shaken from hyacinth roots.

Species: 46.

Station 10B. August 10, 1957. Ogren. Ogren field numbers 247 and 248. Night. Fish taken by hook and line with shrimp bait.

Species: 40, 41.

Station 11. Caño Moro, about 5 miles from inlet. September 9, 1956. Ogren. Ogren field number 176. Afternoon. Water deep, fresh, creek steep-banked. Fish collected with hook and line.

Species: 40.

Station 12. Tortuguero river, about 6 miles from inlet. August 26, 1956. Ogren. Ogren field number 136. Fish found dead near river.

Species: 10.

Station 13. Tortuguero river, about 8 miles from inlet. August 26, 1956. Ogren. Ogren field number 134. Mid-afternoon. Water fresh, highly turbid, brown stained. River in flood, current 2-3 mph. River, running through a river-swamp forest (no hardwoods), about 30-40 yards wide at point of collection. Spiny palm most abundant shore vegetation. Fish collected near shore. Cichlids, under hyacinths, taken with hook and line and shrimp bait. *Eleotris* shaken from hyacinth roots.

Species: 41, 43, 49.

Station 14. Small creek emptying into lagoon about ½ mile from inlet. Water clear, bottom sandy. Depth 1-3 feet. Dense *Potomogeton.*

Station 14A. August 19, 1958. Ogren. Ogren field number 461. Low tide. Fish collected with rotenone.

Species: 14, 17, 20, 31, 36, 43, 53.

Station 14B. September 3, 1958. Ogren. Ogren field number 475. Incoming tide. Fish collected with rotenone.

Species: 6, 7, 14, 15, 17, 18, 25, 26, 43, 49, 51, 52, 53, 55.

ANNOTATED LIST OF FISHES

Unless otherwise stated, in listing the specimens of each species, the first figure is the University of Florida Collections catalog number, the next, the number of specimens in the lot, the third (in parentheses) their size range (standard length) in millimeters, and finally, the station at which the fishes were collected.

CARCHARHINIDAE

1. *Carcharhinus* sp.

One specimen, approximately 5½ feet long, not saved, was taken at Station 2A; another shark, possibly also this genus, was taken at Station 4D. Teeth, UF 7173, Station 2B.

The first specimen was tentatively identified as *Carcharhinus leucas* (Müller and Henle) by Archie Carr, who caught the fish. His identification was based on a general familiarity with this species and with the keys and descriptions of sharks (studied later from memory) from BIGELOW and SCHROEDER (4). His identification is corroborated by the ecological and geographical data presented for this species by BIGELOW and SCHROEDER (4 : 341-43). The teeth are tentatively identified as this species also—by Stewart Springer, United States Fish and Wildlife Service.

CLUPEIDAE

2. *Sardinella anchovia* Valenciennes [1]

UF 5655, 9 (67 to 83), 1A.

3. *Harengula pensacolae caribbaea* Rivas

UF 5653, 14 (69 to 102), 1A.

4. *Opisthonema oglinum* (Lesueur)

UF 5654, 14 (66 to 98), 1A

ENGRAULIDAE

5. *Anchoviella* sp.

UF 5651, 1 (77), 1A.

Based on HILDEBRAND'S (15) keys ot the anchovies, this specimen would be identified as *A. pallida* (Starks). However, since it differed somewhat from HILDEBRAND'S description of *A. pallida,* the Costa Rican specimen was sent to Dr. Daniel Cohen, then of Stanford University, who compared it with the holotype of *A. pallida.* He has kindly given permission for his measurements to be included here, and they appear as Table 1. Since the Tortuguero example is in some ways more like *A. venezuelae* Fowler than *A. pallida,* Hildebrand's (15 : 135) measurements of the holotype and paratype of *A. venezuelae* are included in Table 1 for comparison. The Costa Rican specimen differs from the others, but since the differences seem to be of a lesser magnitude than those between *A. pallida* and *A. venezuelae* —which HILDEBRAND considered synonymous— no nameable taxonomic significance is presently ascribed to them. However, with the collection and study

[1] With the exception of *Oostethus lineatus* which follows, all references to a single author in species described by "Cuvier and Valenciennes" follow BAILEY (1).

of adequate samples of all three forms, three taxons may prove warranted. If, in reality, *A. pallida*, *A. venezuelae*, and the Tortuguero specimen are synonymous, the latter specimen apparently constitutes a range extension from Caño Guanoco, Venezuela (FOWLER, 12 : 407) to northern Caribbean Costa Rican, a shoreline distance of approximately 2000 miles.

TABLE 1

Selected counts and body proportions for three forms of Anchoviella *from Central and South America*

Character	*A.* sp.[1] (76.5 mm.)	*A. venezuelae*[2] (58 mm.) holotype	(63 mm.) paratype	*A. pallida* holotype (82 mm.)[1]	(80 mm.)[2]
Dorsal fin rays	14 or 15	14	12	14	14
Anal fin rays	24	25	26	24	24
Pectoral fin rays	14	13	12	13	13
Gill rakers on first left arch	37 + 45	33 + 40	—	—	34 + 45
Scale Rows	39	34	36	ca. 38	ca. 38
Standard length/ Character Specified					
Depth	3.3	3.8	3.9	3.6	3.5
Head	3.1	3.4	3.5	3.5	3.5
Postorbital head length	5.0	6.3	6.1	6.3	5.9
Anal base	4.7	3.6	3.5	3.7	3.5
Dorsal base	6.2	—	—	7.4	—
Predorsal length	1.9	—	—	1.9	—
Preanal length	1.6	—	—	1.6	—
Head length/ Character specified					
Snout	5.7	6.0	6.0	6.2	6.4
Horizontal diameter of eye	3.4	4.3	4.2	4.2	4.5

[1] Counts and measurements by Daniel M. Cohen
[2] Counts and measurements from Hildebrand (1943: 134-135)

6. *Anchoa lamprotaenia* Hildebrand

UF 7192, 1 (58), 6M; UF 7193, 1 (65), 6N; UF 7190, 288 (39-64), 14B.

Live-color notes made by Ogren show that the fishes have a silver cheek and lateral stripe. The body is white below the stripe, rather transparent above, and has scattered black pigment spots on the dorsum and posterioventer portions—in the latter region extending to the anal fin.

OPHICHTHIDAE

7. *Myrophis punctatus* Lütken

UF 7181, 3 (88-105), 14B.

CHARACIDAE

With the exception of UF 7134, identified by Caldwell, all of the material in this family was identified by James E. Böhlke of the Academy of Natural Sciences of Philadelphia.

8. *Hyphessobrycon tortuguerae* Böhlke

UF 5741, 1 (39.0), 4C, holotype; UF 5836, 3 (24.2-24.8), 4C, paratypes; ANSP 80986, 2 (26.8, 27.5), 4C, paratypes; ANSP 80987, 1 (27.5), 4C, paratype (cleared and stained).

This species was described from the Tortuguero material and discussed in detail by BOHLKE (6).

9. *Astyanax fasciatus æneus* (Günther)

UF 5727, 23 (21-64), 3; ANSP 80858, 12 (20-78), 3; UF 5740, 3 (24-45), 4C; UF 5834, 1 (78), 4D; UF 5744, 4 (46-61), 6E; ANSP 80860, 1 (60), 6E; UF 5751, 2 (43, 47), 6F; ANSP 80859, 2 (49, 61), 6F; UF 5835, 2 (62, 72), 6H; UF 7134, 9 (56-69), 6S.

The anal fin ray counts (by BOHLKE for the ANSP specimens, by Caldwell for the UF material) for these specimens were as follows; the last two rays, split to the base were counted as one:

iv,24	iv,25	iv,26	iv,27	iv,28	iv,29
3	17	16	17	3	3

Live-color notes made by Ogren show that the caudal, anal, and pelvic fins were brick red, with the upper and lower portions of the first and the leading edges of the latter two fins even brighter (and darker) than the rest of the fin. The dorsal and pectoral fins, while red, were much less intensely so. The dorsal portion of the body was metallic black, and the dark stripe on the caudal peduncle very conspicuous.

SYNBRANCHIDAE

10. *Synbranchus marmoratus* Bloch

UF 5799, 1 (about 150 mm total length), 12.

The specimen, mangled as if by a terrestrial predator, was found well back from the river on the forest floor.

POECILIIDAE

11. *Mollienesia sphenops* (Valenciennes)

UF 5782, 17 (25-68), 3; UF 5795, 32 (21-49), 4C; UF 5666, 35 (14-65), 6A; UF 5768, 2 (each 28), 6D; UF 5780, 1 (32), 6E; UF 5767, 2 (16, 19), 6F; UF 5827, 30 (25-74), 6H; UF 7151, 1 (51), 6L; UF 7145, 2 (15, 68), 6M; UF 7139, 1 (78), 6N; UF 7133, 4 (30-38), 6S.

Counting the last two rays, split to the base, as one, a sample of these specimens shows the following dorsal fin-ray counts:

8	9	10
9	41	3

As pointed out by CARR and GIOVANNOLI (9 : 17), the relationships of this species complex are still questionable, and though a number of subspecies have been described, no subspecific designation is definitely assigned the Tortuguero specimens. By description and geographical locale, the Tortuguero material fits well the nominal subspecific form *M. s. tropica* (Meek) as discussed by MEEK (25 : 117).

12. *Phallichthys pittieri* (Meek)

UF 5820, 4 (27-39), 4C; UF 5797, 1 (43), 6D; UF 5823, 1 (33), 6H.

In eye diameter and length of head, the specimens from Tortuguero more closely resemble *Poeciliopsis isthmensis* Regan than *P. pittieri* (see REGAN, 32 : 996-97). However, HUBBS (17 : 71), after examining series of both nominal forms, placed *P. isthmensis* in the synonomy of *P. pittieri,* and his decision is followed here. He also suggests (HUBBS, 16:10; 17:70) that both these forms may prove to be identical with *Phallichthys* [= *Poeciliopsis*] *amates* (Miller).

13. *Belonesox belizanus* Kner

UF 5807, 1 (32), 6H.

No previous record has been found for this species in Costa Rica.

BELONIDAE

14. *Strongylura marina* (Walbaum)

UF 7175, 8 (224-392), 7B; UF 7180, 2 (139, 160), 14A; UF 7186, 3 (168-204), 14B.

These specimens were tentatively identified by Frederick H. Berry, and the following comment is his: "In having 15 to 16 dorsal fin rays (modally 15), dorsal origin over 4th or 5th ray of anal fin, and the absence of a narrow dark raised line on the peduncle, these specimens are distinguishable, according to BREDER (7 : 24), from *Strongylura timucu* (Walbaum), their apparent closest relative. However, according to available literature, *S. timucu* would be the expected species in Costa Rica and if the identification of these specimens is correct, they apparently constitute a range extension in the western Atlantic from the continental waters of the United States".

HEMIRAMPHIDAE

15. *Hyporhamphus roberti* (Valenciennes)

UF 5375, 1 (117), 7A; UF 7174, 16 (87-186), 7B; UF 7185, 1 (70), 14B.

These specimens were identified by Frederick H. Berry, who is presently making a taxonomic study of this family in the western North Atlantic.

There is apparently no previous record for this species from Costa Rica. MILLER (29) states that it occurs from Panama southward, though BEEBE and TEE-VAN (2 : 63) listed it from Bermuda (as *H. hildebrandi* Jordan and Evermann) and JORDAN, EVERMANN, and CLARK (21 : 198) stated that it extends in its range north to Rhode Island, in the United States. Robert R. Miller writes that he collected specimens (now in the United States National Museum) in Guatemala in 1946-47.

PLEURONECTIDAE

16. *Citharichthys spilopterus* Günther

UF 5787, 2 (31, 42), 3; UF 5766, 1 (60), 6F; UF 7195, 3 (43-92), 6S.

SOLEIDAE

17. *Trinectes maculatus fasciatus* (Lacépéde)

UF 7178, 1 (17), 14A; UF 7187, 1 (19), 14B.

18. *Achirus lineatus* (Linnaeus)

UF 7188, 1 (25), 14B.

SYNGNATHIDAE

19. *Oostethus lineatus* (Valenciennes) [2]

UF 5833, 1 (83), 4F; UF 7191, 1 (77), 6M; UF 7194, 4 (79-90), 6N.

UF 5833 differs from the characters for this species as presented by HERALD (14 : 134) in that it has only 18 tail rings, while he gives a range of 23 to 27 in his key. Three of the other five Tortuguero specimens have 22 tail rings, and the other two 23. Three specimens of *O. lineatus* from the northern Atlantic coast of Florida (UF 6835, 6836, and 1811) were compared and the latter two were found to have 22 tail rings, while the first had 23. Of eight specimens from the Yateras River in Cuba (UF, uncataloged), two had 22, five had 23, and one had 24 tail rings. It is thus apparent that the range of variation in this character for this species of pipefish must be clarified.

20. *Pseudophallus mindii* (Meek and Hildebrand)

UF 7179, 3 (62-91), 14A.

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[2] Rather than Valenciennes *in* Cuvier and Valenciennes, this should be cited as Valenciennes *in* Kaup, 1856, *fide* JORDAN and EVERMANN, 19 : 773

ATHERINIDAE

21. *Coleotropis* sp.

UF 5652, 1 (76), 1A.

This specimen, which is clearly a *Coleotropis* as defined by MYERS and WADE (30 : 136) and SCHULTZ (34 : key to genera of atherinids), seems to differ significantly from the only two nominal species presently ascribed to this genus - *C. blackburni* Schultz from Venezuela, and *C. starksi* (Meek and Hildebrand) from the Pacific coast of Panama. However, since all of the differences found are proportional, and thus possibly attributable to age or abnormality, and since only one specimen is at hand (despite serious efforts by Ogren to obtain others during the summers he was collecting), no specific name is presently applied to it. A detailed description (by Caldwell) is herewith presented and a photograph appears as Figure 2. Counts and measurements were taken and recorded in the manner described by SCHULTZ (34 : 5).

By comparing measurements of the Tortuguero specimen (76 mm) and the holotype (82 mm) and a paratype (45 mm) of *C. blakburni*—the latter two sets of figures from SCHULTZ (35 : 106)—the Costa Rican specimen differs markedly in the relationship of depth to standard length (16% as compared to 18.9 and 21. 2% for *C. blackburni* the character increasing with length in the latter species. Differences in the least depth of the caudal peduncle in relation to standard length (9 % in *Coleotropis* sp. as compared to 9.9 and 9.6 % for *C. blackburni*—the character also increasing with length in the latter species) and the length of the caudal peduncle (22 % of standard length in *Coleotropis* sp. as compared to 20.6 and 20.7% in *C. blackburni*) are much less marked, but contribute to the overall illusion of slimness in *Coleotropis* sp. It should be noted especially that the 76-mm Costa Rican fish is still slimmer than the 45-mm. specimen of *C. blackburni.* Thus since it more closely approaches in size the 82-mm specimen of *C. blackburni.* the proportional differences between the two larger fishes should be considered particularly significant. The Tortuguero specimen is a much slimmer fish than *C. blackburni.*

Detailed measurements of the Tortuguero fish are presented in Table 2. Also included in the table are the same measurements expressed as percent of standard length and as the number of times they may be divided into standard length. The measurements were taken with dividers and a ruler.

The following counts were made: Dorsal rays IV - 1, i, 7; anal rays 1, i, 21; pectoral rays i, 13 on each side; pelvic rays 1, 5 on each side; 15 branched caudal rays. 46 scale rows from the head to the mid-caudal base; 5 rows between the origin of the first dorsal fin and the lateral line and 4 rows between the lateral line and the anal fin origin.

Seven scales between the bases of the dorsal fins. 16 zig—zag rows of scales around the least depth of the caudal peduncle. Gill rakers 3 + 1 +16 on the first right gill arch.

TABLE 2

Selected measurements and body proportions for a 16 mm. Coleotropis *from Tortuguero, Costa Rica*

Character	Empirical Length (mm.)	Character as % of Standard Length	Standard Length/ Character
Head	16	21	4.8
Greatest depth	12.5	16	6.1
Snout	5	7	15.2
Bony orbit	4.5	6	16.9
Postorbital head length	7.5	10	10.1
Interorbital width	4.5	6	16.9
Caudal peduncle	16.5	22	4.6
Depth of caudal peduncle	6.5	9	11.7
Greatest head width	8	11	9.5
Pelvic insertion to anal origin	11	14	6.9
Snout to first dorsal origin	41.2	54	1.8
Snout to second dorsal origin	52	68	1.5
Snout to anal origin	39	51	1.9
Snout to pectoral insertion	19.9	26	3.8
Origin of first dorsal fin to origin of second dorsal fin	11	14	6.9
Anal fin origin to center of anus	3.5	5	21.1
Longest firts dorsal fin ray	5	7	15.2
Longest second dorsal fin ray	9.5	13	8.0
Longest anal fin ray	11	14	6.9
Longest pectoral ray	12	16	6.3
Longest pelvic fin ray	8.5	11	8.9
Last second dorsal ray	4.3	6	17.7
Depressed second dorsal fin	11.5	15	6.6
Depressed anal fin	25	33	3.0
Base of second dorsal fin	7	9	10.9
Base of anal fin	20.5	27	3.7
Accessory pelvic scale	3	4	25.3
Snout to pelvic fin origin	28.5	38	2.7
Snout to pectoral fin origin	17	22	4.5

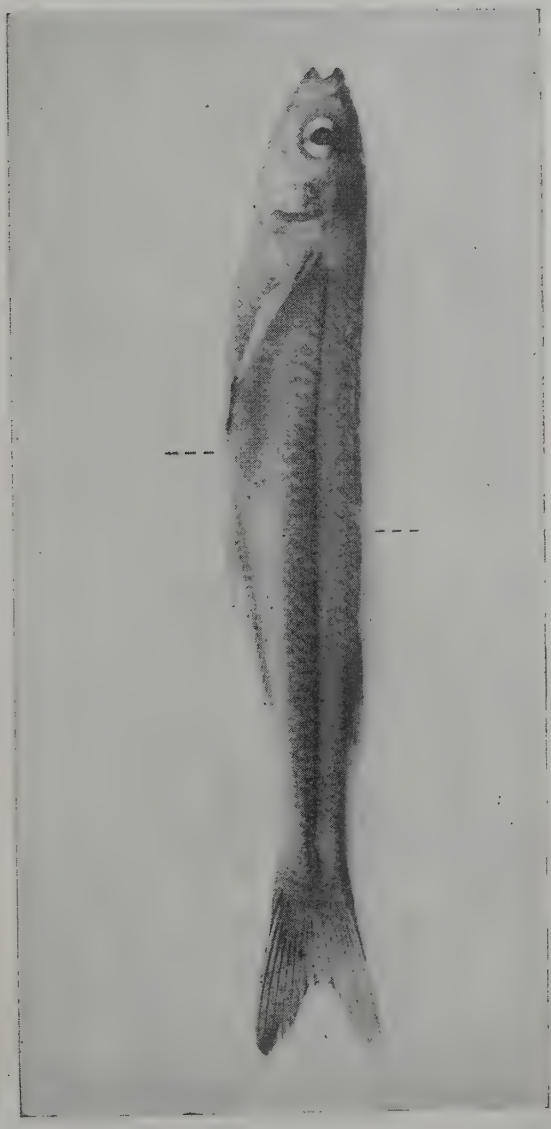

Fig. 2: *Coleotropis* sp., 76 mm. in standard length, UF 5652, from Tortuguero, Caribbean Costa Rica. Dotted lines indicate position of spinous dorsal origin and anus.

Into the length of the head, the snout may be divided 3.2 times, the orbit 3.6, the interorbital 3.6, and the postorbital 2.1 times.

The subjective description of *C. blackburni* (SCHULTZ, 35 : 108) fits the Tortuguero specimen in all respects except for the relationship of depth of caudal peduncle to its length (2 ½ in *Coleotropis* sp. as compared to less than 2 in *C. blackburni)* and the silver color of the lateral stripe. The silvery lateral stripe (band) is not present as such on the Tortuguero individual. Instead, it appears as a brown stripe which may, through an artifact of preservation, be all that remains of the silvery stripe. The brown band occupies exactly the same position on the fish, and has the same proportional relationships, as the silver one on *C. blackburni.* The other characters of dark pigment (as described by Schultz, 1949: 109) are the same on the Costa Rican specimen as they are on the Venezuelan ones.

One of the largest paratypes of *C. blackburni* was examined (on loan from the United States National Museum through the kindness of Dr. Schultz) by Caldwell and no differences other than noted above were readily discernible.

Coleotropis sp. differs from *C. starksi* in the depth of the body (much less in the former) and in the characters which distinguish *C. starksi* from *C. blackburni.*

The single specimen was taken on the open beach, and as none was taken in the river and lagoon nearby and since Ogren did not actually collect in the open surf, the lack of success noted above in obtaining other specimens is possibly more a function of restricted ecological niche than actual rarity of the form in Costa Rica. MEEK and HILDEGRAND (27) did not list atherinids presently ascribed to *Coleotropis* from the Atlantic side of Panama, and Loren Woods writes that up to 1958 no specimens have been received by him from Panama. FOWLER (13) lists no *Coleotropis* from Colombia, nor have I seen any records for it anywhere in the Caribbean other than that of SCHULTZ (35 : 108). This apparent discontinuity in range between Venezuela and Costa Rica will perhaps be significant in determining the relationship between the Tortuguero specimen and *C. blackburni.* If, however, with the study of significant samples of both forms, they prove synonymous, the Costa Rican fish must represent a range extension of the Venezuelan one of approximately 1200 shoreline miles.

22. *Thyrinops chagresi* (Meek and Hildebrand)

UF 5786, 39 (41-92), 3; UF 5809, 5 (35-60), 5; UF 5811, 8 (29-54, 101, 103), 6B; UF 5793, 2 (42, 51), 6E; UF 5805, 12 (41-79), 6I; UF 5821, 4 (32-77), 6J; UF 7159, 2 (86, 94), 6K; UF 7148, 14 (39-83), 6L; UF 7142, 3 (52-90), 6M; UF 7141, 3 (95-98), 6N; UF 7171, 6 (99-106), 7B.

The use of the generic name *Thyrinops* Hubbs is based on the recent revisionary work of SCHULTZ (34 : 28). JORDAN and HUBBS (22 : 59) place the species in the genus *Thyrina* Jordan and Culver. MYERS and WADE (30 : 138) note this genus name is preoccupied, however, and show that *Melaniris* Meek should be applied to the species formerly included in *Thyrina.* SCHULTZ (34 : 30) restricts *Melaniris* to include a single Pacific drainage species, leaving *Thyrinops* as the next available generic name for the remaining species of *Thyrina.*

MEEK and HILDEBRAND (27 : pl. 20, fig. 1) are apparently in error in depicting the location of the origin of the first dorsal fin of their species. As they note in their description (p. 267), and as seen on the Tortuguero specimens, this fin originates well back of the anal fin origin.

Fish-eating bats (*Noctilio*) were seen (by Ogren) to prey on this species at Tortuguero. The method of hunting as exhibited by these bats has been described and illustrated in detail by BLOEDEL (5).

MUGILIDAE

23. *Mugil curema* Valenciennes

UF 5837, 5 (26-27), 3; UF 7158, 1 (258), 6K; UF 7168, 1 (199), 6T.

Although small, the specimens in UF 5837 agree closely with the characters for Central American *Mugil* as presented by MEEK and HILDEBRAND (27), and comparison with similar-sized specimens of *M. curema* from Georgia and closely-related *M. incilis* from Panama prove the identity of the small Costa Rican specimens to be the former species. William W. Anderson has made extensive studies on small mullets, and the initial identification is his. He collaborated with Caldwell on the final decision as to proper specific designation for these specimens. The large specimens clearly belong to this species.

POLYNEMIDAE

24. *Polydactylus virginicus* (Linnaeus)

UF 5656, 1 (45), 1A.

CARANGIDAE

All of the specimens in this family were identified by Frederick H. Berry, who has recently completed a comprehensive study (BERRY, 3) of young *Caranx* in the Western North Atlantic.

25. *Caranx latus* Agassiz

26. *Caranx hippos* (Linnaeus)

UF 5726, 5 (45-56), 3; UF 5848, 1 (51), 14B.
UF 5844, 2 (260, 297), 2B; UF 5847, 2 (44, 48), 14B.

27. *Oligoplites palometa* (Cuvier)

UF 5845, 3 (284-323), 2B.

CENTROPOMIDAE

28. *Centropomus ensiferus* Poey

UF 5828, 1 (20), 6F.

Since the specimen is quite small, the specific name *C. ensiferus* is assigned tentatively. However, based on a combination of characters given for members of this genus in the keys by MEEK and HILDEBRAND (28 : 419 f.) and SCHULTZ (35 : 115), the following counts made on the Tortuguero specimen seem to place this young individual to species: Dorsal VIII - 1, 10; anal III, 6; scales about 45-50 along the side; all gill rakers on lower limb of first arch 16.

29. *Centropomus pectinatus* Poey

UF 7152, 1 (42), 6L; UF 7160, 1 (61), 6M; UF 7161, 1 (38), 6N, UF 7167, 2 (40, 48), 6S.

30. *Centropomus parallelus* Poey

UF 7163, 1 (93), 6N; UF 7153, 1 (84), 6Q.

LUTJANIDAE

31. *Lutjanus jocu* (Bloch and Schneider)

UF 5843, 1 (120), 4E; UF 7143, 1 (37), 6M; UF 7157, 1 (138), 6Q; UF 5817, 1 (185), 8; UF 5850, 2 (18, 20), 14A.

RIVAS (33 : 152) notes that this species often ascends fresh waters.

POMADASYIDAE

32. *Pomadasys crocro* (Cuvier)

GERRIDAE

UF 5784, 27 (32-50), 3.

33. *Diapterus rhombeus* (Cuvier)

UF 5773, 4 (40-62), 3; UF 7147, 1 (36), 6L; UF 7146, 2 (39, 41), 6M; UF 7137, 4 (33-36), 6N; UF 7130, 9 (29-48), 6S.

In using the name *Diapterus rhombeus,* we follow SCHULTZ (35), much of whose discussion on gerrids is based on the unpublished revisionary work of Luis R. Rivas.

34. *Diapterus olisthostomus* (Goode and Bean)

UF 7149, 1 (56), 6L; UF 7135, 1 (49), 6N.

35. *Eugerres* sp.

At station 6M, Ogren collected a 203 mm gerrid which, on the basis of color (as noted by SCHULTZ, 35) appears to have belonged to this genus. Unfortunately, the specimen did not preserve properly and was discarded without gill-raker and fin-ray counts being made. According to Ogren, its total length was 223 mm, greatest depth 102 mm, and head length 65 mm. It had 13 distinct brown lateral stripes above, and 14-15 obscure ones below. The pelvic fins were yellow-orange toward the center; the anal similar in color, but less intense; the pectorals colorless; and the dorsal and caudal blue-black.

36. *Eucinostomus pseudogula* Poey

UF 5790, 2 (40, 46), 3; UF 5778, 1 (25), 5; UF 5829, 3 (22-29), 6C; UF 7144, 5 (34-56), 6M; UF 7136, 5 (39-62), 6N; UF 7131, 1 (42), 6S; UF 7169, 3 (15 each), 14A.

As for the other species in this family, I follow SCHULTZ (35). If the key to the genus *Eucinostomus* as presented by CURRAN (11) is utilized, the Costa Rican specimens would be identified as *E. melanopterus*.

SCIAENIDAE

37. *Ophioscion costaricensis* Caldwell

UF 5831, 1 (117), 1B, holotype; UF 5830, 1 (110), 1B, paratype.

This species was described from Tortuguero material and discussed in detail by CALDWELL (8).

38. *Micropogon furnieri* (Desmarest)

UF 5838, 4 (193 - 239), 9.

39. *Bairdiella ronchus* (Cuvier)

UF 5839, 5 (158-196), 9.

CICHLIDAE

40. *Cichlasoma friedrichsthali* (Heckel)

UF 5667, 5 (63-116), 4B; UF 5660, 1 (110), 6A; UF 5798, 3 (21-64), 6D;

UF 7166, 1 (96), 6R; UF 7128, 7 (28-117), 6S; UF 5816, 2 (144, 153); 8; UF 5840, 1 (107), 10B.

The specimens from Tortuguero agree well with the descriptions and keys presented for Central American cichlids by REGAN (31) and for Costa Rican cichlids by MEEK (25). HUBBS (18) and CARR and GIOVANNOLI (9) have discussed the relationships of this species with others closely allied to it.

The local name for *C. friedrichsthali* is "Guapote".

41. *Cichlasoma citrinellum* (Günther)

UF 5785, 1 (61), 3; UF 5819, 1 (84), 4D; UF 5810, 2 (20, 76), 5; UF 5659, 1 (86), 6A; UF 5792, 1 (55), 6E; UF5791, 3 (42-60), 6F; UF 5813, 1 (81), 6G; UF 5825, 3 (25-63), 6H; UF 7154, 1 (92), 6Q; UF 7126, 4 (33-71), 6S; UF 5841, 1 (139), 10B; UF 5802, 1 (111), 13.

MEEK (25 : 125) notes that this species had not been taken in lowland streams of Costa Rica, being listed as occurring in the highlands at an altitude of over 3000 feet and abundant in the Nicaraguan lakes Managua and Nicaragua. These specimens authenticate his speculation that it shold occur in lowland streams.

The local name for this species is "Crana".

42. *Cichlasoma centrarchus* (Gill and Bransford)

UF 5789, 1(75), 3; UF 5822, 2 (19, 62), 5; UF 5561, 3 (15-35), 6A; UF 7132, 1 (42), 6S.

The Tortuguero specimens fit well the descriptions and keys given by REGAN (31) and MEEK (24). Though both these authors list the habitat of *C. centrarchus* as the nearby Lake Nicaragua, no previous record has been found for its occurrence in Costa Rica.

43. *Cichlasoma maculicauda* Regan

UF 5803,1 (75), 4D; UF 7155, 1 (43), 6Q; UF 7129, 1 (64), 6S; UF 5818, 3 (150-191), 8; UF 5801, 2 (180, 182), 13; UF 7170, 5 (24-29), 14A; UF 7182, 143 (10-12), 14B.

MEEK (25 : 127) noted that this species had not yet been recorded from Costa Rica, but stated that since it occurs in lowland streams and sometimes brackish water, in Guatemala and Panama, it should be expected in similar habitats in Costa Rica.

Ogren noted that 2 large adults of this species were in their vicinity when the very small individuals from station 14B were collected, perhaps indicating parental care by this species.

The Mosquito-indian name for this species is "Tuba", which means "Friend". The name is in reference to the almost universal availability of the fish in the area, and the indian along the river feels that as long as he has his ever-carried handline and some sort of bait (usually some of the shrimps which abound in the roots of the water hyacinths) he will not starve.

44. *Herotilapia multispinosa* Günther

UF 5662, 2 (80, 91), 6A.

DACTYLOSCOPIDAE

45. *Dactylagnus* sp.

UF 7176, 1 (44), 1C.

A description of this specimen, representing an undescribed form, will be published elsewhere at some future date by Böhlke and Caldwell.

ELEOTRIDAE

46. *Dormitator maculatus* (Bloch)

UF 5806, 2 (35, 45), 4F; UF 5663, 28 (10-53), 6A; UF 7150, 3 (16-19), 6L; UF 7138, 1 (45), 6N; UF 5808, 1 (65), 8; UF 5842, 1 (75), 10A.

These specimens seem to belong to the large-headed group of this species as described by JORDAN and EVERMANN. (20 : 2196)

47. *Gobiomorus dormitor* Lacépéde

UF 5783, 4 (36-61), 3; UF 5665, 1 (21), 6A; UF 5770, 1 (44), 6E; UF 5769, 2 (54, 56), 6F; UF 5826, 3 (50-82), 6H; UF 7162, 1 (101), 6N; UF 7127, 2 (85, 89), 6S.

48. *Eleotris pisonis* (Gmelin)

UF 7164, 1 (280), 6P; UF 5765, 1 (87), 8.

49. *Eleotris amblyopsis* (Cope)

UF 5788, 2 (32, 41), 3; UF 5669, 2 (20, 21), 4B; UF 5763, 2 (58, 67), 4F; UF 5775, 18 (24-67), 5; UF 5664, 43 (14-70), 6A; UF 5774, 3 (22-35), 6C; UF 5832, 1 (62), 13; UF 5849, 12 (19-47), 14B.
UF 5776, 3 (24-33), 6F; UF 5782, 1 (34), 6H; UF 7156, 1 (66), 6Q;

No reason was found, on the basis of available literature, to distinguish this species from *E. isthmensis* Meek and Hildebrand. The characters which they give for their new species (MEEK and HILDERBAND, 26 : 359) seem to overlap those given for the older-named *E. amblyopsis* by JORDAN and EVERMANN (20 : 2199).

50. *Microeleotris mindii* Meek and Hildebrand

UF 7196, 4 (34-42), 6S.

GOBIIDAE

51. *Garmannia spes* Ginsburg

UF 5779, 2 (23, 24), 5; UF 5670, 1 (23), 6A; UF 7184, 1 (20), 14B.

52. *Evorthodus lyricus* (Girard)

UF 5771, 1 (37), 4C; UF 5764, 2 (25, 32), 5; UF 7189, 1 (35), 14B.

53. *Gobionellus claytonii* (Meek)

UF 5804, 14 (20-49), 3; UF 5796, 2 (23, 31), 4C; UF 5800, 4 (26-51), 5; UF 5794, 3 (28-41), 6E; UF 5777, 1 (25), 6F; UF 7177, 4 (10-28), 14A; UF 7183, 12 (26-44), 14B.

ECHENEIDAE

54. *Echeneis naucrates* Linnaeus

UF 5657, 1 (155), 2A; UF 7172, 2 (111, 170), 2B; UF 5814, 1 (174), 4D.

TETRAODONTIDAE

55. *Sphoeroides testudineus* (Linnaeus)

UF 5772, 1 (87), 3; UF 5668, 3 (90-122), 4A; UF 5658, 1 (92), 6A; UF 5812, 4 (92-103), 6G; UF 5824, 1 (99), 6H; UF 7140, 2 (70, 121), 6N; UF 7165, 3 (70-124), 6P; UF 5846, 3 (41-50), 14 B.

RESUMEN

Se presenta una lista anotada de peces recogidos en las cercanías de Tortuguero, en la costa atlántica de Costa Rica, durante los meses de julio a septiembre de 1955 por L. Giovannoli y de 1956-58 por L. H. Ogren, o por compañeros de éstos. Las localidades descritas se indican en el mapa, fig. 1; junto a la descrip-

ción de las condiciones en que se hizo cada colección se anotan las especies recogidas, numeradas según la lista sistemática presente. Al enumerar las especies en esta última, se indican las localidades, el número de ejemplares en cada colección, la longitud en milímetros, a menos que se indique otra cosa, de la punta del hocico a la base de los radios caudales medios.

LITERATURE CITED

1. Bailey, R. M.
1951. The authorship of names proposed in Cuvier and Valenciennes' "Histoire Naturelle des Poissons" *Copeia,* 1951, 3 : 249-251.

2. Beebe, W., & J. Tee-Van.
1933. *Field book of the shore fishes of Bermuda.* New York: G. P. Putnam's Sons, pp. vii-xvi + 1-337, illus.

3. Berry, F. H.
[MS] *Development, distribution, and identification of young jack crevalles* (Caranx) *off the Atlantic coast of the southeastern United States.* U. S. Fish and Wildlife *Serv.*, Fish. Bull., *in press.*

4. Bigelow, H. B., and W. C. Schroeder.
1948. Sharks. *In* Tee-Van, J.; *Fishes of the western North Atlantic.* New Haven: Sears Foundation, Bingham Oceanogr. Lab., pp. 59-576.

5. Bloedel, P.
1955. Hunting methods of fish-eating bats, particularly *Nocteilio leporinus. Jour. Mammal.,* 36, (3) : 390-399.

6. Böhlke, J. E.
1958. Studies on fishes of the family Characidæ. N° 16. A new *Hyphessobrycon* from Costa Rica.
Bull. Florida State Mus., Biol. Sci., 3 (4): 173-178, 1 fig.

7. Breder, C. M., Jr.
1932. On the habits and development of certain Atlantic Synentognathi.
Papers from Tortugas Lab., 28, (1) : 1-35, 10 figs., 12 pls.

8. Caldwell, D. K.
1958. A new fish of the genus *Ophioscion,* family Sciaenidæ, from Caribbean Costa Rica. *Quart. Jour. Florida Acad. Sci.* 21 (2): 117-124, 1 fig.

9. Carr, A., & L. Giovannoli
1950. The fishes of the Choluteca drainage of southern Honduras. *Occas. Pap. Mus. Zool., Univ. Michigan,* No. 523, pp. 1-38, 2 pls.

10. Carr, A., & L. Giovannoli
1957. The ecology and migrations of sea turtles, 2. Results of field work in Costa Rica, 1955. *Amer. Mus. Novitates,* No. 1835, pp 1-32.

11. Curran, H. W.
1942. *A systematic revision of the gerrid fishes referred to the genus* Eucinostomus, *with a discussion of their distribution and speciation.* Unpublished doctoral dissertation, University of Michigan.

12. Fowler, H. W.
1931. Fishes obtained by the Barber Asphalt Company in Trinidad and Venezuela in 1930. *Proc. Acad. Nat. Sci. Philadelphia*, 83: 391-410.

13. Fowler, H. W.
1953. The shore fishes of the Colombian Caribbean. *Caldasia*, 6 (27): 43-73.

14. Herald, E. S.
1942. Three new pipefishes from the Atlantic coast of North and South America, with a key to the Atlantic American species. *Stanford Ichthyol. Bull.*, 2 (4) : 125-134.

15. Hildebrand, S. F.
1943. A review of the American anchovies (Family Engraulidae). *Bull. Bingham Oceanogr. Coll.*, 8, art. 2: 1-165.

16. Hubbs, C. L.
1924. Studies of the fishes of the order Cyprinodontes. *Univ. Michigan Mus. Zool., Misc. Publ.*, No. 13: 1-31, 4 pls.

17. Hubbs, C. L.
1926. Studies of the fishes of the order Cyprinodontes. VI. *Univ. Michigan Mus. Zool,. Misc. Publ.*, No. 16: 1-87.

18. Hubbs, C. L.
1935. Fresh-water fishes collected in British Honduras and Guatemala. *Univ. Michigan Mus. Zool., Misc. Publ.*, No. 28: 3-22, 4 pls., 1 map.

19. Jordan, D. S., & B. W. Evermann.
1896. The fishes of North and Middle America. *Bull. U. S. Natl. Mus.* 47, pt. 1, p. i-lx + 1-1240.

20. Jordan, D. S., & B. W Evermann
1898. The fishes of North and Middle America. *Bull. U. S. Natl. Mus.* 47, pt. 3, pp. v-xxiv + 2183[a]-3136.

21. Jordan, D. S., B. W. Evermann, & H. W. Clark
1930. Check list of the fishes and fishlike vertebrates of North and Middle America north of the northern boundary of Venezuela and Colombia. *Rept. U. S. Comm. Fish.*, 1928, pt. 2: 1-670.

22. Jordan, D. S., & C. L. Hubbs
1919. Studies in Ichthyology. A monographic review of the family of Atherinidae or silversides. *Leland Stanford Junior Univ. Publ., univ. ser.*, pp. 1-87, 12 pls.

23. Kaup, J. J.
1856. *Catalogue of the lophobranchiate fish in the collection of the British Museum.* London, 1856. (Ref. copied).

24. Meek, S. E.
1907. Synopsis of the fishes of the Great Lakes of Nicaragua. *Field Columbian Mus., Zool. Ser.*, 7 (4): 97-132.

25. MEEK, S. E.
1914. An annotated list of fishes known to occur in the fresh waters of Costa Rica. *Field Mus. Nat. Hist., Zool Ser.*, 10 (10) : 101-134.

26. MEEK, S. E., & S. F. HILDEBRAND
1916. The fishes of the fresh water of Panama. *Field Mus. Nat. Hist., Zool. Ser.*, 10 (15) : 217-374.

27. MEEK, S. E., & S. F. HILDEBRAND
1923. The marine fishes of Panama. *Field Mus. Nat. Hist., Zool. Serv.*, 15 (1) : v-xi + 1-330.

28. MEEK, S. E., & S. F. HILDEBRAND
1925. The marine fishes of Panama. *Field Mus. Nat. Hist., Zool. Ser.*, 15 (2) : xv-xix + 331-707.

29. MILLER, R. R.
1945. The use of the names *Hyporhamphus roberti* and *Hyporhamphus hildebrandi* for the same halfbeak fish of tropical America. *Copeia*, 1945 (4) : 235.

30. MYERS, C. S., & C. B. WADE
1942. The Pacific American atherinid fishes of the genera *Eurystole, Nectarges, Coleotropis*, and *Melanorhinus*. *Allan Hancock, Pacific Exped.* 9 (5) : 113-149, 3 pls.

31. REGAN, C. T.
1906-08. Pisces. *In Biologia Centrali-Americana*, 8: i-xxxiii + 1-203, 26 pls.

32. REGAN, C. T.
1913. A revision of the cyprinodont fishes of the subfamily Poeciliinae. *Proc. Zool Soc., London*, 58 (4) : 977-1018, 3 pls.

33. RIVAS, L. R.
1949. A record of lutjanid fish (*Lutjanus cyanopterus*) for the Atlantic coast of the United States, with note on related species of the genus. *Copeia*, 1949 (2) : 150-152.

34. SCHULTZ, L. P.
1948. A revision of six subfamilies of atherine fishes, with descriptions of new genera and species. *Proc. U. S. Natl. Mus.*, 98 : 1-48, 2 pls.

35. SCHULTZ, L. P.
1949. A further contribution to the ichthyology of Venezuela. *Proc. U. S. Natl. Mus.*, 99 : 1-211, 3 pls.

BIBLIOGRAPHY

In addition to the papers noted in the section on Literature Cited, many of which were helpful in identifying species other than those for which the paper is cited, the following publications were found to be particularly useful in the study of the Tortuguero material. The combined lists also summarize the majority of the papers which deal directly with the ichthyofauna of Costa Rica.

FOWLER, H. W.
1903. Notes on a few fishes from the Mosquito Coast of Nicaragua. *Proc. Acad. Nat. Sci. Philadelphia,* 55: 346-350.
1916. Cold-blooded vertebrates from Costa Rica and the Canal Zone. *Ibid.* vol. 68, pp. 389-414, 4 figs.
1923. Fishes from Nicaragua. *Ibid.,* vol. 75, pp. 23-32.

GINSBURG, I.
1932. A revision of the genus *Gobionellus* (Family Gobiidæ). *Bull. Bingham Oceanog. Coll.,* vol. 4. art. 2, pp. 1-51.
1933. A revision of the genus *Gobiosoma* (Family Gobiidae) with an account of the Genus *Garmannia. Ibid.,* vol. 4, art. 5, pp. 1-59.
1944. A description of a new gobiid fish from Venezuela, with notes on the genus *Garmannia. Jour. Wash. Acad. Sci.,* vol. 34, no. 11, pp. 375-380.

GÜNTHER, A.
1868. An account of the fishes of the states of Central America, based on collections made by *Capt. J. M. Dow, F. Godman, Esq.,* and *O. Salvin, Esq. Trans. Zool. Soc. London,* 6 (7): 377-494, pls. 64-87, 1 map.

HILDEBRAND, S. F.
1925. Fishes of the Republic of El Salvador, Central America. *Bull. U. S. Bur. Fish.,* 41:237-287.
1938. A new catalogue of the fresh-water fishes of Panama. *Field Mus. Nat. Hist., Zool. Ser.,* 22 (4): 215-359.

JORDAN, D. S., & B. W. EVERMANN.
1898. The fishes of North and Middle America. *Bull. U. S. Natl. Mus.,* 47 (2): i-xxx + 1241-2183.
1900. [Same title] *Ibid.,* no. 47, pt. 4, pp. i-ci + 3137-3313.

MEEK, S. E.
1906. Description of three new species of fishes from Middle America. *Field Columbian Mus., Zool. Ser.,* 7 (3): 93-95.
1908a. Notes on fresh-water fishes from Mexico and Central America. *Ibid.,* vol. 7, no. 5, pp. 133-157.
1908b The zoology of Lakes Amatitlan and Atitlan, Guatemala, with special reference to ichthyology. *Ibid.,* vol. 7, no. 6 pp. 159-206.
1909. New species of fishes from tropical America. *Ibid.,* vol. 7, no. 7, pp. 207-211.
1912. New species of fishes from Costa Rica. *Field Mus. Nat. Hist., Zool. Ser.,* 10, (7): 69-75.

MEEK, S. E., & S. F. HILDEBRAND.
1912. Descriptions of new fishes from Panama. *Field Mus. Nat. Hist., Zool. Ser.,* vol. 10, no. 6, pp. 67-68.
1913. New species of fishes from Panama. *Ibid.,* vol. 10, no. 8, pp. 77-91.
1928. The marine fishes of Panama. *Ibid.,* vol. 15, pp. xxv - xxxi + 709-1045.

NORMAN, J. R.
1934. *A systematic monograph of the flatfishes* (Heterosomata). *Vol. 1.* Psettodidae, Bothidae, Pleuronectidae. London: British Museum (Natural History), viii + 459 pp., 317 figs.

PARR, A. E.
1930. Teleostean shore and shallow-water fishes from the Bahamas and Turks Island *Bull. Bingham Oceanographic Coll.*, 3, (4): 1-148, 38 figs.

RIVAS, L. R.
1950. A revision of the American clupeid fishes of the genus *Harengula*, with descriptions of four new subspecies. *Proc. U. S. Natl. Mus.*, 100: 275-309.

SCHULTZ, L. P.
1945. Three new sciaenid fishes of the genus *Ophioscion* from the Atlantic coasts of Central and South America. *Proc. U. S. Natl. Mus.*, 96: 123-137.

STOREY, MARGARET.
1938. West Indian clupeid fishes of the genus *Harengula* with notes on *H. thrissina* from the Pacific coast. *Stanford Ichthyol. Bull.*, 1 (1): 3-56.

The Use of Radioisotopes in Studies of the Foods and Feeding Activities of Marine Animals.

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(con 1 tavola fuori testo)

Because of the nature of the marine environment, the foods and feeding of the great majority of the animals of the sea are quite different from those of animals living on land. Marine animals are ultimately dependent on the photosynthetic activity of the green plants. In the sea the light necessary for this process is limited to the uppermost water mass. For the great expanse of the open oceans, the green plants of the upper few hundred feet serve as the primary source of food for all the animal life. These are the minute unicellular algae. Their small size assists in preventing their sinking to the darker lower levels and provides a large surface area for the direct absorption of the nutrient chemicals which are present in the water in dilute amounts. For the most part, the larger marine animals and fishes are not able to feed on these small plants. They are dependent on other animals possessing feeding mechanisms enabling them to utilize the minute plant cells. We have, therefore, a vast number of small animals of the plankton that feed on the phytoplankton directly. These, in turn, may serve as food for many of the larger animals and fishes. Some fish, however, feed on smaller fish, and still others on bottom animals. These bottom-dwelling forms are themselves dependent of the plankton, either as living organisms or as organic particles following their death and settling to the bottom. Some bottom forms feed on other bottom-dwelling animals, but all are ultimately dependent on the phytoplankton of the upper water layers. This dependency of the various types of marine animals on the phytoplankton has been well depicted by CLARKE (1954) in his diagram of the fundamental food cycle of the sea.

Generally the food chains of the animals of the sea are not simple. It is perhaps more descriptive to speak of these complexities as a food web. Of the commercially important fishes, the menhaden is one of the few species which can feed on the small sized phytoplankton. In this species, however, the larvae require more than a two link food chain and feed by capturing the small animals of the plankton. The complexity of the food web is realized when one considers

the variety of organisms constituting the diet of different fishes and the various chains involved in each of the food organisms eaten. It is further complexed by the fact that the type of food organism eaten by the fish changes at different periods in its life history. Although difficult to follow, an understanding of the various parts of the food web is important in furthering our knowledge of the biology of commercially important fish and shellfish.

Characteristic of these primary consumers in the food chains of the sea is the development of various means of propelling water through different types of filtering mechanisms and the sorting and gathering of the food particles removed. The copepods, which are important members of the animal plankton, have special appendages bearing a net of bristles which efficiently remove small particles from the water passed through this filtering mechanism. Sessile bottom-dwelling animals have many specialized structures for the filtration of food particles. By ciliary action pelecypod molluscs, such as the oyster and clam, propel large quantities of water through their gills. The water passes through small openings of the gill filaments into water tubes and thence into the cloaca. Some of the suspended particles are removed by the gills and transported to the mouth and into the digestive tract. Other particles, sorted from the food, are discarded. The mechanisms of filtration, transport, and sorting are complex.

In obtaining answers to some of the problems involved in studied of the filtration feeding of the primary consumers of the phytoplankton, radioisotopes may be used advantageously. They can be used in ascertaining the food organisms of certain species, the efficiency of particle filtration, the factors affecting this efficiency, and in tracing the pathways of selection, ingestion, and digestion of suspended organic particles.

The selection of a radioisotope for labeling phytoplankton or particles for use in such studies of transport and movement is based primarily on its physical characteristics. It should emit particles or rays of sufficient energy to be detected and measured conveniently and accurately when the radioisotope is present in very small amounts. It should have a half-life, that is, the length of time for the radioactivity to decrease to half its original value, sufficiently long to allow its use in the experiments planned. Most important of all, it must be one that can be readily incorporated into or attached to the particles to be traced and retained by the particles when suspended in sea water during the experiment.

In considering the methods of labeling particles with radioisotopes for use in experiments on the foods and feeding of marine animals, it will be well to review certain characteristics peculiar to tracer methodology. A number of these enter into the problem of the incorporation of the radioactive label into the particle to be traced and the retention of the radioactivity by the tagged particle. Of particular importance are surface adsorption and the phenomena of exchange.

Since we are often dealing with particles of very small size, surface area in relation to mass is great. Because of the nature of the charges on such surfaces, chemical elements present in small concentrations are often strongly adsorbed. Surface adsorption of the radioisotope of an element may be particularly great if it is present in carrier-free solution, that is, a solution in which all the atoms of the element present are radioactive. The advantage of using a carrier-free radioisotope for the labeling of certain particles is obvious.

The phenomena of exchange enter into both the uptake and the loss of the radioactive tag. Very early in the use of radioisotopes as tracers it was demonstrated that there was an interchange of atoms between two chemical combinations.

An alteration of the isotopic ratio of the element in one chemical combination through the addition of some radioactive atoms may result in the transfer and incorporation of some of the radioactive atoms in another chemical combination. Through exchange there is a tendency to approach an isotopic equilibrium of the elements in each chemical combination in which the specific activity, the ratio of radioactive to total atoms of the element present, is the same. To prevent a great loss of the radioisotope from the labeled particles from exchange when resuspended in sea water, it is desirable to incorporate the radioactive tag into a non-exchangeable chemical form.

Techniques for surface labeling sand and hard pebbles by adsorption of a layer of an element on the sand, followed by a baking process to stabilize the material, have been recently investigated. Such labeled tracers are being employed to great advantage to study the movement of such particles as silt, sand, and pebbles in errosion of shore areas and deposition of fill in channels of harbors and estuaries. Carrier-free barium-140, separated from its daughter product, lanthanum-140, has been recently used by SMITH & EAKINS (1957) for following flint pebble movement on beaches. It is a suitable tracer, a low energy γ-emitting isotope (half-life 12 days) with consequent ease of handling and the high energy γ-radiation of the lanthanum-140, which builds up with a half-life of 40 hours, provides for detection of small amounts of the radioactive material.

In studies of the rate of filling and the movement of silt in New York Harbor, the Corps of Engineers of the U. S. Army are currently using labeled ground glass. In these studies the element scandium, which has a favorable cross-section area for neutron bombardment, is incorporated into glass. Following irradiation, the radioisotope Sc^{46} serves as a tracer for the particles of ground glass.

Although the use of labeled particles, such as finely ground glass, precipitates, or colloidal suspensions, may serve well for certain studies on the foods and feeding of marine animals, living organisms which have been labeled with a radioactive material have been used in most of the investigations. When radioactive plankton forms are used, there is virtually no alteration of the food

materials given to the test animals and the different species or types of plankton may be compared as to their nutritive value. It is possible to compare the food usage of a certain species when present with others in a mixed suspension. Often the small planktonic forms remain better suspended in the sea water than do many inorganic particles.

In labeling small living organisms, such as phytoplankton cells, with radioisotopes, both surface adsorption and exchange may play important parts. Metabolism, with alteration in the concentrations of exchangeable and non-exchangeable chemical compounds, can be a factor in the obtaining of a satisfactory tagged living cell.

If an element is present within a cell in a concentration very much greater than that in the surrounding sea water, and this is present in a readily exchangeable form, it is possible to obtain cells containing a high concentration of a radioisotope of that particular element. This would result from the great difference in the concentrations of the total element in the sea water and within the cell and the establishment, through exchange, of like specific activities of the radioisotope in the two. On resuspending such radioactive cells in sea water containing the element without the radioisotope, some loss would take place through exchange. If the total element in the sea water was present in very low concentrations, the loss would not be appreciable.

Metabolism within the living cell may alter the uptake and retention of a radioisotope since new chemical compounds are being formed. As a result there may be an increase or a decrease in the concentrations of compounds in which the atoms are readily exchangeable. The incorporation of the radioisotope into compounds which are not exchangeable through metabolism is important in the labeling of living phytoplankton cells with certain isotopes, for example, with P^{32}.

In the case of phosphorus, it has been demonstrated conclusively a great number of times using the isotope P^{32} that there is no chemical exchange between the inorganic P^{32} and atoms bound in organic combinations. It is only through metabolic pathways that this radioisotope can be incorporated into the various organic compounds.

The labeling of phytoplankton cells with phosphorus-32 was studied in our laboratory in connection with investigations of the food and the feeding activities of lamellibranch molluscs. It was necessary to have labeled cells with high concentrations of radioactivity and that the radioactivity be retained by these cells when resuspended in sea water. Consequently, studies were undertaken (RICE, 1953) of the phosphorus exchange in marine phytoplankton. A rather detailed description of this work will explain further the non-metabolic and metabolic uptake of phosphate from nutrient solutions and the obtaining of a labeled phy-

toplankton food organism containing considerable amounts of P^{32} in the non-exchangeable fraction.

In this particular study, RICE employed unialgal and bacteria-free cultures of the marine diatom, *Nitzschia closterium*, grown in enriched sea water under controlled conditions of light and temperature. Inorganic phosphorus concentrations were determined by the colorimetric molybdate method using a photoelectric colorimeter. The cell populations were measured from microscopic counting of the cells of an aliquot in a haemocytometer counting slide. The phytoplankton cells were removed from the culture medium through filtration onto a freshly-prepared barium sulfate precipitate supported on a filter paper disc. The filtering apparatus was a separable one made of stainless steel which allowed for removal of the filter paper and filtered cells. Most of the radiological measurements were made using an aliquot of the filtrate. In instances where the radioactivity of the cells was to be determined, they were dissolved in a small amount of nitric acid, water was added, and the diluted acid counted.

The radiological measurements were made of the P^{32} in solution using 25-ml. volumes in a 50-ml. centrifuge tube. A glass walled dip-type Geiger-Mueller counting tube was immersed to a constant depth and connected to a conventional scaler. Background counts, made with non-radioactive acid solutions, were subtracted and the results corrected for decay of the P^{32}.

When radioactive phosphorus was added to the enriched sea water with *Nitzschia* cells and the culture grown in the light, the phosphorus entered the cells until it was reduced below a concentration detectable with the colorimetric method. However, radiological measurements for labeled phosphorus made at the end of the experiment showed that a trace of phosphorus still remained in the medium. There is a possibility that this trace of radiophosphorus was present due to exchange.

To detect exchange, radioactive phosphorus was incorporated into the cells and the cells washed on the filter with a medium which was like that in which the cells had been grown except for the addition of P^{32}. If an exchange of phosphorus occurs, the radioactive phosphorus leaving the cells will be removed before it can be reabsorbed by the cells. The appearance of P^{32} in the medium would indicate that phosphorus was being exchanged between the cells and medium. Since the washing medium had the same concentration of phosphorus as the medium in which the cells had been growing, except for a few atoms of P^{32}, no differentiation could have been made between phosphorus originally in the washing medium or in the cells without the use of the radioactive tracer.

Loss of radioactive phosphorus to the medium showed that the cells exchanged phosphorus with the medium when filter-washed. The cells grown in the presence of a high concentration of phosphorus absorbed more phosphorus

and exchanged more phosphorus than those grown in medium containing much less of the element.

KETCHUM (1939) has shown that phytoplankton cells grown in a medium low in phosphorus become deficient and contain only a small fraction of the amount of phosphorus found in non-deficient cells, and, also, that more phosphorus is absorbed by deficient cells when again placed in medium containing phosphorus. Using phosphorus deficient cells, RICE demonstrated that these physiologically different *Nitzschia* cells not only took up more phosphorus from the medium when the element was again made available, but they also exchanged less phosphorus, due likely to more of the phosphorus taken into the cells during this time being converted into the organic state.

In other experiments, RICE separated the phosphorus of the cells into organic and inorganic fractions using the usual fractionation scheme obtaining trichloracetic soluble and insoluble portions, and separation of the orthophosphate from soluble organic phosphorus compounds with $CaCl_2$ in saturated $Ca(OH)_2$. He demonstrated that there was continued incorporation of P^{32} into the organic compounds with time and that the P^{32} of the exchangeable inorganic fraction became small in amount as compared to the non-exchangeable P^{32} of the organic compounds of the cell.

It was thus possible to obtain *Nitzschia* cells of high radioactivity, which would be retained well when the cells were resuspended in non-radioactive sea water, by using phosphorus deficient cells grown in a new medium containing P^{32} of very high specific activity for a sufficiently long period of time. Later many other species were labeled in like manner following studies of the particular metabolic conditions providing for a high incorporation of the P^{32} into organic combinations in each particular species.

The possibilities of labeling phytoplankton cells with other selected isotopes has been investigated, but only to a very limited extent. On occasion it has been desired to label a second species of plankton in order to feed suspensions of mixed algal populations to marine animals. We have made use of Ca^{45} for this purpose. There remains, of course, many other radionuclides that would prove useful.

A number of studies have been conducted at our laboratory on the foods and feeding of lamellibranch molluscs; oysters, clams, and scallops, using radioactive plankton cells. To a very limited extent we have observed the feeding activities of a marine copepod and other filter-feeding invertebrates, and of a marine fish, the menhaden. Much of our work, however, has been with the uptake and accumulation of fission product radionuclides and the passage of these through various food chains leading to the economically important fish and shellfish. It would be difficult to enumerate and give credit to all the researchers that have contributed to these studies, much of the data of which

are not yet published. The chief contributors to those phases of the work dealing with the foods and feeding mechanisms, however, were T. R. RICE, T. J. PRICE, REBECCA J. SMITH, & D. J. FLOYD.

Our investigations on the foods and feeding of lamellibranch molluscs may be described as illustrative of the applications of radioisotope techniques to obtain answers to some of the problems involved in such studies. Some of our earlier work dealt with the selectivity of food particles and the utilization of certain plankton species by the American oyster, *Crassostrea virginica*. Observations on the gill efficiency of oysters, the hard shell clam, *Venus mercenaria*, and the bay scallop, *Pecten irradians* have been made.

Before considering the experimental work on the foods and feeding activities of the oyster, it would be well to review briefly some of the anatomy of the oyster and its mechanisms of feeding.

While feeding, the oyster depends on a continuous propulsion of water through its gills from which food particles are removed and passed to the mouth. The beating of the cilia of the cells covering the folds and tubes of a complex water system is responsible for the flow. The water is swept through small openings in the gills, called ostia, and passes into the water tubes and into the cloacal chamber. During this passage some of the particles suspended in the water are filtered and retained by the gills. Cilia carry the large particles filtered by the gills to the ventral groove where they intangle in mucus and the mass is apt to be discarded. Smaller particles are carried along the dorsal groove to the palps, ciliated folds of tissue outside the mouth opening, where a more intensive sorting takes place. The sorting mechanisms are by no means perfect and the oyster may reject some good food material and ingest worthless particles. The rejected material, bound in mucus, is deposited ventrally in masses of what is known as pseudofeces. The true feces leaves the rectum, which lies along the adductor muscle, in a rather continuous thread of packed material and is discharged through the cloacal chamber posteriorly in the region of flow of the excurrent water.

Besides the sorting of filtered particles by size, other physical characteristics may cause their rejection by the oyster. Spiny organisms may be rejected and smooth one-celled organisms accepted. Large quantities of suspended particles reaching the filtering organ at one time may cause an increased activity of the mucous secreting cells and bring about increased rejection of all particles. Very little is known about the chemical sensitivity of the feeding mechanisms within the oyster, but certain types of particles or species of plankton stimulate mucous secretion and affect the feeding process.

It should be pointed out that the fecal material of oysters will contain numbers of living plankton cells that have been swept through the digestive tube undamaged and in a living condition. The digestive capabilities of oysters

are quite limited. Even though possible food particles, such as species of phytoplankton labeled with the radioisotope P^{32}, pass through the mouth into the digestive tract, there is question as to whether or not they will be digested and utilized. In tracer studies some of the P^{32} of the feces may be of endogenous origin, but a great amount is likely to be still within the non-utilized plankton cells.

Many investigators have based their measure of utilization of certain species of plankton by oysters on growth measurements, an unfed group serving as control. However, the use of radioisotope tracer techniques in such studies offers distinct advantages. If certain plankton organisms labeled with a radioisotope as a tracer are fed to oysters and supply the only source of that particular radionuclide, any radioactivity found on analysis of the tissues is proof that the oyster has broken down the labeled plankton organisms and assimilated the element.

As an illustration of the use of radioisotopes in studies of the acceptability of certain species of plankton by the oyster and their utilization as a food, I will describe the experimental work done at our laboratory on these problems. Some of the results were given in a paper presented at the annual meeting of the National Shellfisheries Association in New York in 1952 (Floyd, 1952).

In the first group of experiments, the oysters were placed in containers of standing aged sea water. Tracings on a kymograph drum recorded the shell movements and the hours the oyster was open. Three feedings of plankton cells labeled with P^{32} as previously described were made from the addition of a small volume of a heavily populated culture at five-hour intervals. The true feces and the pseudofeces were collected separately prior to each successive feeding and after the last feeding, and the separate collections combined for analysis. Measurement of the cells not filtered by the oyster was made on an aliquot of the suspension left in the feeding dish. After feeding, each oyster was placed in a dish of aged sea water and time allowed for digestion and assimilation. The oysters were then opened and their tissues tested for radioactive phosphorus. Analyses of the radioactivity of the various phosphorus compounds of the adductor muscle were made separately.

In a second group of experiments, in order to avoid varying concentrations of plankton with sudden great increases from the addition of many cells at one time, an arrangement was devised to give a more uniform and continuous feeding. This was accomplished by adding a thickly populated plankton culture dropwise into the feeding vessel. An inverted Erlenmeyer flask having a two hole stopper allowed for one tube for delivery and another for the intake of air. It was found that a third tube, providing for the bubbling of air from a small air pump through the suspension, was highly desirable to provide stirring to keep the plankton cells in suspension. Non-radioactive plankton were fed until a continuous string of feces appeared. Then, over a period of three hours, radio-

active cells were fed at the same population density. Non-radioactive cells were again fed until virtually no radioactivity was present in the feces.

Examination of the control oysters kept in the same medium but in which the plankton cells had been previously removed showed that the radioactivity could not have been the result of direct absorption of the P^{32}. The medium contained almost no radioactive phosphorus, 95 to 99.5 percent being in the plankton cells, and the control oysters did not have any appreciable radioactivity in their tissues.

It was possible to account for the radioactive plankton cells added to the container in which the oyster was fed. Such an accounting is important, for there is a tendency for the cells to settle and to stick to the bottom and sides of the container. Also, the cells remaining in suspension and not filtered by the oyster need be considered.

The various samples were brought into solution with nitric acid and their P^{32} content was measured with a dip-type Geiger-Mueller tube. The results were corrected for decay of the P^{32} to the time of the start of the feeding when the cell population of the feeding suspensions was determined.

The species of plankton used included two diatoms, *Nitzschia closterium* (56 microns in length) and *Skeletonema costatum,* a filamentous form (5 by 9 microns in size). Three chlorophyceae were fed. These included a species of *Chlorella* (1.7 by 3.3 microns in size) and two flagellated species, one of a *Carteria* (11 by 13 microns in size) and one of a *Chlamydomonas* (7 microns in size). One ciliated protozoan was used, *Plagiocampa marina* (9.5 by 25 microns in size).

The acceptability of the various forms by the oyster is evidenced from a comparison of the percentage of the cells fed to the oyster and deposited in the feces and the pseudofeces. The cells of *Chlorella* sp., the smallest fed, were readily accepted by the oysters. Only 16.4 percent of the cells fed were in the pseudofeces and 33.4 percent passed through the digestive tract. When the filamentous diatom *Skeletonema costatum* was fed, 47.1 percent of the cells were in the pseudofeces and only 6.4 percent through the digestive tract. Apparently size, and shape are some of the conditions that determine the acceptability of various plankton cells by the oyster. A great abundance of cells in suspension at one time also influenced the number rejected. These studies need be continued using additional species to give further enlightenment on the sorting of particles by oysters.

One might expect a positive correlation between the number of radioactive cells passing through the digestive tract and the amount of P^{32} present in the tissues of the oysters if digestion and utilization of the ingested material takes place. Conversely, the lack of correlation would suggest that there was no utilization. There was good correlation for most species between the number

of radioactive cells passed through the digestive tract and the P^{32} content of the organic phosphorus compounds of the adductor muscle of the oysters. There was no correlation in the case of feeding with *Chlorella* sp. Even though there were more radioactive cells fed and passed through the digestive tract of some of the oysters, no accumulation of P^{32} took place in the phosphorus-containing compounds of the adductor muscle.

The movement of water through the mantle cavity by lamellibranch molluscs has been studied by many investigators. The rate of water propulsion has been estimated from data on the reduction of the number of particles in a suspension in which the animals have been placed. With oysters, collection of the outflowing water of the cloacal chamber is possible and considerable work has been reported on the factors affecting the rate of pumping using direct measurements of the rate of flow. Since the water passed through the gills can be examined, the efficiency of removal of particles by the gills of oysters may be observed. Radioactive materials can be detected and measured when present in extremely small amounts, and radioisotopes can be incorporated into plankton cells in high concentrations with good retention. Thus the presence of even only a few cells in the water passed through the gills of oysters can be learned and their number accurately measured. We have conducted some studies measuring the number of cells of different species of phytoplankton that have escaped filtration by oysters using cells labeled with P^{32}.

The oyster has a number of mechanisms which control the flow of water through its gills. The current is produced by the beating of the lateral cilia of the gills. The degree of openness of the shell and the position of the mantle edges provide for control of the amount of water entering. In the gills the ostia regulate passage of water into the water tubes.

The so-called « apron » method for measuring directly the rate of pumping of water by oysters allows all the regulatory processes to function undisturbed and the oyster is observed under comparatively normal conditions. Partial wrapping of the oyster in thin rubber sheeting to channel the cloacal current into a separate container was suggested to the author by Dr. THURLOW NELSON. He has shown (NELSON, 1936) that this experimental procedure does not interfere with the normal behavior of the oyster. We have made use of such a rubber cone and GALTSOFF's constant level chamber (GALTSOFF, 1926) for collecting the excurrent water of oysters for a variety of experimental purposes for many years. Tav. VII shows an oyster in such a chamber.

The basic experimental arrangement, which has since been modified by numerous improvements, was described by GALTSOFF, CHIPMAN, HASLER & ENGLE (1938). A piece of rubber dam, similar to that used by dentists, is patterned in such a way that it forms a conical shape when wrapped around an oyster, extending away from the excurrent side. The end of the cone is left

open. The rubber dam is cemented tightly to the oyster along a built up and smoothed ridge over the irregular shell surfaces. Sufficient slack is left at the posterior margin to allow the valves to part freely. Into this slack region is inserted a plug of cotton to prevent water from escaping to the incurrent side. The oyster, equipped in this manner, will, when feeding, discharge all the water into the rubber cone.

The oyster is then placed in a constant level chamber. Actually, the vessel has two compartments connected by a tube or trough. One of larger size than the other serves as the feeding chamber. The smaller compartment receives the water leaving the oyster. The small end of the rubber cone is tightly attached to the connecting tube or trough so that all water leaving the oyster is directed into the collecting compartment. The outlet of the latter is of a stand-pipe type. The feeding compartment has an overflow cut along one side of rather large size so that the sea water or suspensions fed the oyster can be flowed rapidly through the chamber, at least faster than the maximum pumping rate of the oyster. The setup is so adjusted that, with the oyster in place, and the feeding sea water flowing but with the rubber cone not fastened to the connecting trough, no water moves down the outlet stand-pipe of the collecting chamber. However, the addition of water to the collecting chamber does result in an overflow, drop for drop. Various devices have been used to collect and measure automatically the discharged water.

We have used this rubber apron method for measuring the escapement of radioactive planktonic algae to the excurrent water from passage through the gills. It is interesting to note that, in 62 tests using several different oysters, there were no instances in which the gills retained all the cells. However, the largest cells used were those of a species of *Carteria*, one of the Chlorophyceae, measuring 10 by 14 microns. There appeared to be a greater percentage of the small *Nannochloris atomus* cells not filtered from the water passing throungh the gills than for the cells of the larger species. The feeding of a dense population of these 100×10^6 cells per liter, resulted in almost no retention by the gills in many instances. There was some indication that the oyster removed a greater percentage of the cells when present at moderate population densities than when the cells were fed in either high or low concentrations. The presence of another species of phytoplankton in the suspension of *Nannochloris* fed resulted in a more efficient removal of the small *Nannochloris* cells. This may have been due to some closing of the pores of the gills from filling with the larger cells.

In the case of many lamellibranchs, and in many species of filter-feeding marine invertebrates and fishes, direct measurements of the volume of water put through the filtering mechanism are virtually impossible. Calculations of the rate has been made in many instances from data on the rate of decrease of particles in the suspension in which the filtering animals have been placed. The use of

suspended plankton with photoelectric determination of changes in concentration resulting from the activity of the animals was suggested by JØRGENSEN (1943). He later reported on some experiments in which diatoms labeled with P^{32} were employed (JØRGENSEN & GOLDBERG, 1953).

With the availability of methods of labeling plankton cells with radioactive isotopes and the extremely accurate techniques of measuring small changes in cell numbers, and particularly for the counting of cells in sea water at very low populations, it was advantageous to employ these methods in our studies of the filtration rates of filter-feeding marine animals.

If one assumes that the organism is filtering the water efficiently with complete removal of the suspended particles, the rate of filtration will equal the rate of water propulsion. Data obtained on the decrease in the number of particles per unit of time can be used to calculate the rate of water flow according to the formula

$$conc_t = conc_o \times e^{-\frac{mt}{M}}$$

in which M is the volume of suspension in liters, m is the quantity of water moved in liters per hour, while $conc_o$ and $conc_t$ are the cell concentrations at the initial time and after t hours of time. The results so obtained may not be the true pumping rate since the original assumption is likely to be incorrect in many instances. Since there is apt to be escapement of some of the plankton through the gills, the measured filtration rate may actually be lower than the true pumping rate. In our studies on the water filtration of the bay scallop, *Pecten irradians*, we used suspensions of different species of phytoplankton cells made radioactive with P^{32} (CHIPMAN, 1954; CHIPMAN & HOPKINS, 1954). The concentrated phytoplankton cultures, or portions of them, were added to an aged sea water to give the desired cell concentration. The number of cells present after dilution was calculated from measurements of aliquots of the concentrated culture using a haemocytometer. Changes in the cell concentration of the suspension were followed by radioactivity measurements of aliquots removed at regular intervals. Since the cell population after dilution could be calculated from the prior exact microscope counting and the radioactivity of the cells accurately measured, any changes in cell population could be detected even though extremely slight. It would be quite impossible to detect such slight changes occurring in short periods of time in dilute suspension using photometric measurements. In fact the original starting concentration was often lower than that which would give differences from sea-water blanks using such an instrument.

The radioactivity of 10-ml. aliquots of the plankton suspension was measured after the addition of nitric acid to disintegrate the cells and dilution to a 25-ml. volume. A dip-type Geiger-Mueller counting tube was used. At first, mea-

surement of the decrease in radioactivity, representing decrease in cell population, was attempted by immersion of the glass counting tube in the suspension and the making of repeated radioactivity measurements. However, there was soon an accumulation of radioactive cells around the tube even though it was coated with a non-wetting agent. Another objection was the limited time of measurement which might not provide enough counts to give the desired accuracy.

After an initial increase in rate of filtration as the scallop became adjusted after immersion, a nearly constant percentage decrease of the suspended phytoplankton took place. As the observations were continued, the decrease in phytoplankton became less and less. This change in rate likely resulted from a changed efficiency of filtration, although it could have resulted from a change in water propulsion. The latter seems unlikely for the scallops appeared to pump considerable amounts of water even though the phytoplankton population did not decrease.

The observations showed that the bay scallop has a relatively high rate of water propulsion, probably correlated with its rapid rate of growth and active mode of life. The average rate for small scallops, 38-44 mm. in length, was 3.26 liters per hour. The larger scallops, about 12 to 14 months of age, and measuring 64-65 mm. in length, averaged 14.72 liters per hour. The maximum rate observed was 25.4 liters per hour.

In rather similar experiments, the filtering efficiency of the hard clam was investigated using species of phytoplankton labeled with P^{32} (Rice & Smith, 1957). In these studies the radioactivity measurements were made of the cells of aliquots of the suspension, separated from the sea water by filtration with slight vacuum onto a membrane filter held in the separable filter holder previously described. These filters, made of a special cellulose product, are very retentative, having a pore size of about a half micron, and are of such a nature that the phytoplankton cells are held on the surface and not throughout the meshes of the filter. This latter fact makes them particularly valuable for radioisotope work, for the material on the filter is in a flat layer at the surface. The filter with the plankton cells may be placed in the bottom of a planchet, or counting dish, and counted below an end-window Geiger-Mueller tube. If required, the filter and cells may be dissolved in nitric acid, dried, and ashed before counting. In a few instances larger filters were employed using a larger sized separable glass filter holder. These filters were then placed in the bottom of a plastic petri dish for radioactivity counting. The counting arrangements were standardized with due considerations of geometry, back-scatter, self absorption, coincidence, etc.

From these tests using radioactive plankton cells in the feeding of clams, it was observed that, in unialgal suspensions, the small cells of either *Nannochloris*

or *Chlorella* were removed at a slower rate than the larger diatom cells. This may mean, as described in the tests on oysters, that the gill efficiency for these small cells is much less than for the larger cells, or, that the observations, always consistant, resulted from changes in the volume of water pumped at different times.

As in the observations on the filtering efficiency of the oyster, the presence of the larger diatom cells in a suspension with the very small cells of *Nannochloris* brought about an increased efficiency in the removal of the small cells. In these tests, only one of the species was labeled with a radioisotope. It was observed also that the efficiency of the clam in removing the larger species of phytoplankton was reduced when cells of the smaller species were present. It would be expected then, in nature, that the efficiency would lie somewhere between that observed for the large cells and for the small cells since natural populations have species of different sizes.

Using radioactive plankton cells it was possible to measure the efficiency of the clam in removing cells when particles of silt or mud were also present in the suspension. Photometric measurements based on turbidity could not be employed for such tests and the value of a radioisotope as a research tool is again apparent. It would have been possible, of course, to devise methods of measuring the abundance of different particles, but the use of isotopes made the tests relatively simple.

Since it was known that the oyster and other lamellibranchs vary the volume of water passed through their filtering mechanisms, it was realized that the measurements made of the rate of water propulsion from the reduction of particles in suspension may not be truly the pumping rate if escapement of cells through the gills took place. Such escapement through the gills of oysters was demonstrated in the tests previously described. Furthermore, differences in the removal of different species of phytoplankton cells observed during tests made at different times might have resulted from a change in the rate of water propulsion rather than to a changed gill efficiency.

Early in the studies the use of mixed suspensions of phytoplankton, each labeled with a different radioisotope tag, was considered. The animals placed in such a suspension of mixed phytoplankton cells would reduce the total population and differences in efficiency of removal of species could be observed following radiological determination of the number of cells of each species remaining. The factor of a change in water propulsion would be ruled out since the cells would be removed from the same water and at the same time by the gills.

There are, of course, a number of ways in which the abundance of each of two radioisotopes can be measured when both are present in the same sample. In fact double labeling is quite common in many different types of investigations.

Even triple or more labeling is possible and may be used to advantage in some instances.

A few observations were made in the investigations on the feeding of oysters in which two species of plankton were employed, each labeled with a different radioisotope. Measurement of the radioactivity due to each isotope in the mixtures of the two were based on calculations involving differences in their decay rates. By allowing time for the radioactivity due to the isotope of short half-life to decay to levels of insignificance, the radioactivity of the other could be determined. Correction of the observed values for the decay of the radioisotope of relatively long half-life made it possible to estimate the contribution of the latter to the total radioactiviy initially observed. However, some difficulties were encountered in experimental procedures and, due to this and other reasons, the study was not continued further.

Miss SMITH of our laboratory has made use of double labeling of phytoplankton cells in a suspension to study the gill efficiency of the clam, *Venus mercenaria*. She has recently reported on some of her findings (SMITH, 1957). She employed species of phytoplankton labeled with either P^{32} or Ca^{45} and estimated cell numbers of each species in a mixed suspension from radioactivity measurements computing the abundance of each isotope through the use of aluminum absorption data.

For measurements of two radioisotopes based on the maximum energy of their β particles, P^{32} and Ca^{45} served very well. P^{32} is a β emitter, has no γ rays, is of suitable half-life (14.3 days), and has a maximum energy of its β particles of 1.701 Mev (millions of electron volts). Ca^{45} is also a pure β emitter, is of long half-life (163 days), and has a maximum energy of 0.254 Mev.

By the interposing of an aluminum absorber of sufficient thickness to stop all the β particles of the Ca^{45} and only a portion of those of P^{32}, the amount of the latter reaching the detector and recorded could be measured. Having determined the percent transmission of the P^{32} through the absorber, its contribution to the total radioactivity measured without the aluminum absorber could be calculated. By subtracting this contribution of the P^{32}, that of the Ca^{45} could be obtained. The value measured for each isotope could be corrected for decay from the time of sampling, which actually was necessary only for the P^{32}. These values represented cell-equivalents, for the radioactivity per cell for each species had been determined at the start of the tests based on microscopic cell counts and the radioactivity of an aliquot of the suspension used in preparation of the diluted feeding mixture. Table 1 shows the measurements and calculations made with a sample in which known amounts of Ca^{45} and P^{32} were mixed.

Mention should be made here of the need for consideration of possible radioactive contaminants in the radioisotope material to be employed. Contaminants of longer half-life than the radioisotope of the test assume greater

importance as the stock material ages. Contaminants of shorter half-life, if their presence is realized, con often be eliminated by allowing time for their decay before use. For example, the P^{32} that we obtain has amounts of P^{33} present

Table I. Example of estimation of P^{32} and Ca^{45} concentrations in a sample of a mixture of the two radionuclides.

(Average of triplicate samples in stainless steel planchets placed below an end-window Geiger-Mueller tube, mica window thickness 1.8 mg./cm^2. Aluminum absorber between samples and detector had a thickness of 43.9 mg./cm^2. Results corrected for coincidence and background).

	Activity in counts per minute			
	P^{32} alone	Ca^{45} alone	Mixture	Calculated
Without absorber . .	14538	3463	17848	$\frac{9902}{.684} = 14477\ P^{32}$
With absorber . .	9948	7	9902	$17848 - 14477 = 3371\ Ca^{45}$
Transmission	68.4 %	0.2 %		

which can contribute appreciable amounts of radioactivity as the shipment ages. P^{33} is a weak β emitter, has no γ rays, has a half-life almost twice that of P^{32} (25 days). Its maximum energy of 0.25 Mev is close to that of Ca^{45}.

In the tests employing P^{32} and Ca^{45}, it was found that the radioactive phosphate in weak acid solution could be used satisfactorily if used promptly on receipt. At this time the contribution of the P^{33} to the total radioactivity was of no significance in the experimental data.

Mention might be made, also, that the presence of radioactive contaminants need be known for another reason. The selective uptake of a contaminant by an organism can lead to erroneous conclusions. For example, measurements of the uptake and accumulation of Sr^{89} by certain species of marine phytoplankton can be complicated by the presence of very small amounts of Sr^{90} in the culture medium. The latter isotope has with it in secular equilibrium its radioactive daughter, Y^{90}. From selective uptake, probably from surface adsorption, the cells removed from a sea water medium containing the Sr^{89} and Sr^{90}-Y^{90} will have a high radioactivity, most of which will decay with a half-life of 2 ½ days since it is due to a selective uptake of the Y^{90}.

There are a number of ways in which the presence of a radioactive con-

aminant can be detected and its identification and concentration determined. The presence of a γ ray may be detected, the decay rate may be altered, or will change, and the characteristic absorption in aluminum or lead may be different. A recent method proposed by HARLEY & HALLDEN (1955) for identification of β-emitting isotopes through aluminum absorption characteristics and estimation of their maximum energy are simpler to use than the usual Feather analysis. β spectrometers or γ-ray spectrometers, if available, may be employed.

In carrying on such tests it was necessary, of course, to study the uptake and retention by the plankton of the isotope to be used. Since the cell population was varied and the number of cells in the sample counted was different at different times, it was necessary to measure the effects of self absorption of the Ca^{45} when different cell numbers were present. From this, knowing the size of the aliquot to be taken and filtered, it was possible to arrange the diluted suspension so that the total cell population never exceeded a certain amount. The maximum number of cells in the aliquot, therefore, would be such that corrections for sample thickness need not be made.

Suspensions of each of the two species of phytoplankton to be used in the feeding experiment were prepared and the cells grown in a continuously lighted cabinet in the presence of either P^{32} or Ca^{45}. After a suitable growth period, aliquots of the suspensions were taken and the cell numbers determined from microscopic counting. The radioactivity of the cells of other similar aliquots was measured, allowing the determination of the radioactivity per cell. The growth suspensions were then diluted to give the desired cell population in the 10 liters of sea water into which each clam was placed. Following the visible opening of the clam and the start of water filtration, aliquots of the feeding suspensions were taken at regular intervals and put through a membrane filter in a separable holder.

The filter with its mixture of two species of radioactive cells was placed in the bottom of a stainless steel planchet. The prior addition of a drop or two of glycerine to the bottom of the planchet kept the filter flat. The filters of a series were counted beneath a thin end-window Geiger-Mueller tube and brought beneath the tube in sequence through the use of an automatic sample changer. After the measurement of the series, an aluminum absorber of the proper thickness was clamped over the bottom of the tube and the series recounted. The results were corrected for coincidence and background and the calculations of the amount of radioactivity due to each radioisotope at the time of sampling calculated as previously explained.

This species of clam, *Venus mercenaria,* was found to remove each species of the larger sizes in the same ratio as they were present in the suspension in almost every instance. In a very few observations one species was removed at a slightly faster rate than the other, especially when the clams first started their

filtering activities. There may be times when some adjustment of the filtering mechanism need be made by the clam when confronted with particles differing somewhat in size. The difference in filtering efficiency was not consistent. More rapid removal of one species at one time might be followed in another observation with a more rapid removal of the other. The removal of the two species in the same ratio as they were present in the suspension took place regardless of the rate of their removal, which varied in different observations. It can be assumed that these differences in rate were due to changes in the water propulsion of the clam with complete removal of all particles of the sizes tested.

When the very small cells of *Nannochloris atomus*, 2 microns in size, were tested in suspensions with the larger *Carteria* cells, the latter were always removed at a more rapid rate. This indicated that the efficiency of the gill for the small cells was less and that some were escaping through the ostia.

MARSHALL & ORR (1955) made use of various species of phytoplankton labeled with P^{32} to obtain information as to their value as food for the copepod, *Calanus finmarchicus*. They also measured the water filtration rate during feeding, digestion of the various food organisms fed, and the assimilation and distribution of the P^{32} in the body following the feeding of phytoplankton labeled with this isotope. They have recently reported further on their work on *Calanus* and other copepods and have included observations using C^{14} as a tracer (MARSHALL & ORR, 1957). Except for some slight modifications in some of the details of the methods employed made necessary by certain characteristics of the experimental animals used, their methods of tracer methodology were quite similar to those previously described in the experimental work with lamellibranch molluscs.

As mentioned previously, copepods are probably the most important members of the zooplankton and form the chief link connecting the primary producers in the sea, the phytoplankton, and the fishes. Investigators of the foods and feeding activities of these small filter-feeding animals have the same basic problems of study as those observing the feeding activities of the filter-feeding molluscs. The use of radioisotope techniques with radioactive particles and phytoplankton are similarly particularly useful.

Using these radioisotope tracer techniques, MARSHALL & ORR found that many different organisms appeared to be suitable for food for copepods. Diatoms were especially good food forms. Those under 5 to 10 microns in size could not be filtered from the suspension. Based on the reduction of radioactive plankton from the feeding, the amount of water filtered per day was observed to vary from less than 1 up to about 80 ml. For *Calanus*, feeding was examined also in the developmental stages using P^{32} labeled cells. Nauplius stages I and II did not feed.

The percentage of the ingested food assimilated was made by making

counts of the radioactivity of the body and the fecal pellets, excretion of dissolved substances was relatively low. Digestion varied from 50 percent up to over 90 percent depending on the type of organism. The fate of the ingested food was followed by testing after dissection. In females a very high percentage of the phosphorus in the food went to the ovary.

In our laboratory we have made a few observations on the feeding of the menhaden, *Brevoortia tyrannus*, which is of great economic importance as a source of marine oil and meal for animal food. In the tests the radioisotope techniques were the same as those employed in studies with other filter-feeding forms. Diatoms and other planktonic forms were fed in suspensions of known densities and their removal from the water by the fish was measured by radioactivity counting. Also, the distribution of the P^{32} passing into the body of the fish from the digestive tract was studied.

Young fish averaging 18.8 cm. in length were able to remove a few phytoplankton cells as small as 2 microns in size (*Nannochloris atomus*). However, the efficiency of removal was very poor as compared to the larger diatoms. Zooplankton forms, such as copepods, were filtered well. Menhaden larvae were unable to feed on phytoplankton cells. They did feed on larvae of the brine shrimp and on copepods, which were taken by individual acts of capture.

It is known that digestion of food by marine fish often is quite slow. Using radioactive phosphorus it was observed that, after a 6-hour feeding period and an 18-hour holding of the menhaden in filtered water, 67 to 93 percent of the P^{32} was still in the intestines and only from 4 to 30 percent in the other organs of the fish.

The experimental work previously described dealt chiefly with the use of radioisotopes to tag the minute food organisms of a number of primary consumers in order to study feeding activities and the selection and use of certain species of food. The use of such radioactive tags may be useful, also, in observations of food selectivity and utilization by a number of small secondary consumers and those animals and fishes higher in the food web, the food materials are much larger and the feeding activities are not complicated. With these larger marine animals and fishes, radioisotope techniques are employed chiefly to follow the uptake and metabolism of elements present in the food or in the surrounding water. In this type of study, the radioisotopes are used as labels for specific elements.

Some studies have been made of the metabolism of certain essential elements by marine forms, particularly those of calcium and phosphorus in the formation of shells. We have investigated the metabolism of the trace metal, zinc, using the radioisotope, Zn^{65} (CHIPMAN, RICE & PRICE, 1957). Pollution of the sea by nuclear-material production plants and from the testing of atomic weapons have brought forth a number of studies of the metabolism of many fission product

elements in marine animals and fishes. These include investigations of the uptake from foods eaten and passage of particular radionuclides through the food chains from the lower organisms to the higher animal forms. Such studies have been the chief activity at our laboratory. Other lectures of this symposium will deal with the use of radioisotopes in metabolic studies with marine or aquatic organisms and the passage of specific elements through the food chains leading to the higher fishes.

Brief mention may be made of some of the future possibilities in the use of radioisotopes in investigations of the foods and feeding of marine animals. The amount of work done in this field to date has been very limited. There are innumerable problems awaiting investigation. We are very lacking in our knowledge of the foods and the nutrient requirements of many of the small phytoplankton grazers on whom some of our important fisheries depend. We need considerable information on the biology of the larval forms of our economically important invertebrates and fishes. An understanding of migrations and the distribution in abundance of certain species may be obtained through a more complete knowledge of the nature of their food and changes in its abundance. Radioisotope techniques can be applied in different aspects of these problems to great advantage.

With new developments in radioisotope techniques, new modes of attack to problems confronting marine biologists are becoming available. New vistas become apparent and problems that seemed unsolvable are now subject to attack using the newer techniques. Improvements in instruments for the detection and measurement of radioisotopes are continually being made. Better phosphors and scintillation counters have made possible the use of more γ-ray emitting isotopes which can be conveniently detected though considerable mass may be interposed between the radioactive material and the detector. Consequently, sample preparations are greatly simplified and *in vivo* experiments become possible allowing continuous measurement on the intact organism during the course of the experiment, and repeated observations in the same organism or group of organisms in culture. Multiple labeling with different isotopes is an extremely useful technique and the possibilities of applying such techniques to problems in marine biology have scarcely been explored. The use of two isotopes of the same element as separate tracers may allow estimation of the particular value of nutrients from different sources. Gamma-ray spectrometers are rapidly becoming common-place equipment in many laboratories and they should prove to be very valuable research tools.

Radioisotopes not now in common use will find wider application. For example, Ca^{47} and Sr^{85} may be conveniently employed to study calcium and strontium metabolism in marine organisms. Measurements of the two isotopes can be made when both are present in the same sample with γ-ray spectroscopy.

Ca^{47} has a rather short half-life, 4.6 days, and has a γ emission. It also has β particles of 0.7 Mev and 2.0 Mev. Sr^{85} is a pure γ emitter with a 65-day half-life. There remain many other isotopes which may be employed advantageously in specific instances.

We have so far only approached in our researches the vast open fields of the application of radioisotopes to marine biology. Development of this great area still lies ahead.

Summary

The importance of plant and animal planktonic micro-organisms is discussed in their role as food for larval stages of larger species of marine organisms. Radioisotopes are shown to be a great help in determining the selectivity of food and its utilisation by fish and molluscs. The use of more than one isotope with different characteristics has considerable advantages for marking different types of micro-organisms eaten; the concentration of each of these after ingestion will can be determined by appropriate tests on the larger animals.

Riassunto

Viene discussa l'importanza dei microorganismi planctonici animali e vegetali come alimento degli organismi marini più grandi specie durante la loro vita larvale. Viene poi illustrato il grande aiuto dei radioisotopi per la determinazione della selettività del cibo e della sua utilizzazione da parte dei pesci e dei molluschi. L'uso di più di un radioisotopo con caratteristiche diverse è assai vantaggioso per marcare diversi tipi di microrganismi che verranno ingeriti negli animali più grandi nei quali poi, mediante tecniche appropriate, si potrà determinare la concentrazione di ognuno di essi.

Bibliografia

CHIPMAN, W. A. — 1954 — On the rate of water propulsion by the bay scallop. — *Proc. National Shellfisheries Assoc., Vol. 45, p. 136-139.*

CHIPMAN, W. A. & J. G. HOPKINS — 1954 — Water filtration by the bay scallop, *Pecten irradians*, as observed with the use of radioactive plankton. — *Biol. Bull., Vol. 107, p. 80-91.*

CHIPMAN, W. A., T. R. RICE & T. J. PRICE — 1957 — Uptake and accumulation of radioactive zinc by marine plankton, fish, and shellfish. — *Fish. Bull. 35, Fish and Wildlife Serv., Vol. 58, p. 279-292.*

CLARKE, G. L. — 1954 — Elements of ecology. — xiv + 534 pp. — *John Wiley & Sons, Inc., New York.*

FLOYD, D. J. — 1952 — Foods and feeding of oysters as observed with the use of radioactive plankton. — *Proc. National Shellfisheries Assoc. 1952, p. 171-180.*

GALTSOFF, P. S. — 1926 — New methods to measure the rate of flow produced by the gills of oysters and other molluscs. — *Science, Vol. 63, p. 233-234.*

GALTSOFF, P. S., W. A. CHIPMAN, A. D. HASLER, & J. B. ENGLE — 1938 — Preliminary report on the cause of the decline of the oyster industry of the York River, Va., and the effects of pulp-mill pollution on oysters. — *Invest. Rept. No. 37, U. S. Bur. Fish., 42 pp. Washington.*

HARLEY, J. H. & N. HALLDEN — 1955 — Analyzing beta absorption graphically to identify emitters. — *Nucleonics, Vol. 13, p. 32-35.*

JØRGENSEN, C. B. — 1943 — On the water transport through the gills of bivalves. — *Acta Physiol. Scand., Vol. 5, p. 297-304.*

JØRGENSEN, C. B. & E. D. GOLDBERG — 1953 — Particle filtration in some ascidians and lamellibranchs. — *Biol. Bull., Vol. 105, p. 477-489.*

KETCHUM, B. H. — 1939 — The development and restoration of deficiencies in the phosphorus and nitrogen composition of unicellular plants. — *J. Cell. Comp. Physiol., Vol. 13, p. 373-381.*

MARSHALL, S. M. & A. P. ORR — 1955 — On the biology of *Calanus finmarchicus.* VIII. Food uptake, assimilation and stage V *Calanus.* — *J. Mar. biol. Ass. U. K., Vol. 34, p. 495-529.*

———— 1957 — Feeding and digestion in marine copepods. — *Abstract 137, International Conference on Radio-isotopes in Scientific Research, United Nations Educational, Scientific, and Cultural Organization, Paris, Sept. 1957.*

NELSON, T. C. — 1936 — Water filtration by the oyster and a new hormone effect upon rate of flow. — *Proc. Soc. Exper. Biol. Med., Vol. 34, p. 189-190.*

RICE, T. R. — 1953 — Phosphorus exchange in marine phytoplankton. — *Fish. Bull. 80, Fish. Bull. Fish and Wildlife Serv., Vol. 54, p. 77-89.*

RICE, T. R. & R. J. SMITH — 1958 — Filtering rates of *Venus mercenaria* (L.) determined with radioactive plankton. — *Fish. Bull. 29, Fish and Wildlife Serv., Vol. 58, p. 73-82.*

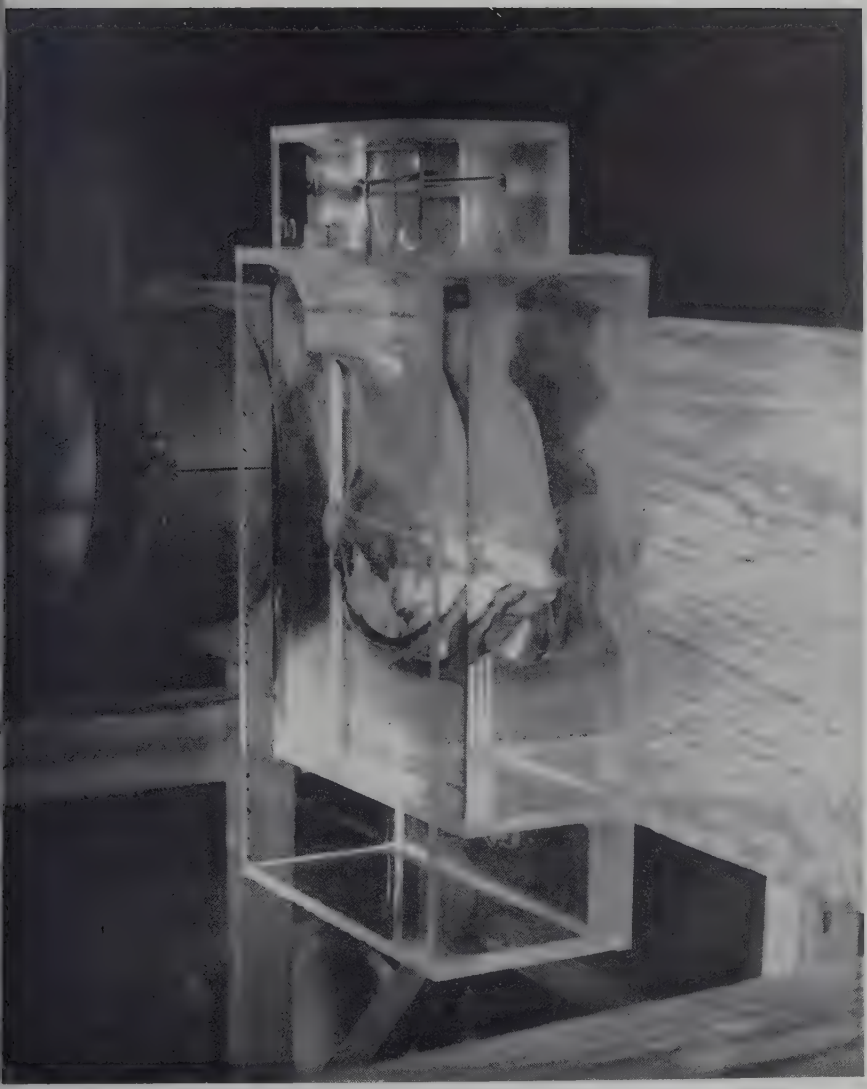
SMITH, D. B. & J. D. EAKINS — 1957 — Radioactive methods for labelling and tracing sand and pebbles in investigations of littoral drift. — *Abstract 63, International Conference on Radio-isotopes in Scientific Research, United Nations Educational, Scientific, and Cultural Organization, Paris, Sept. 1957.*

SMITH, R. J. — 1958 — The filtering efficiency of hard clams in mixed suspensions of radioactive phytoplankton. — *Proc. National Shellfisheries Assoc., Vol. 48, p. 115-124.*

Spiegazione della tavola fuori testo.

TAV. VII

An oyster partially wrapped in a rubber membrane and placed in a chamber through which a flow of sea water is maintained. The water filtered by the oyster enters the unwrapped side, passes through the gills, and leaves the cloacal chamber of the oyster through the rubber cone into a collecting chamber. A standpipe overflow in the collecting chamber maintains a water level equal to that in the chamber in which the oyster is placed.



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DANIEL M. COHEN

THE SCIENTIFIC NAME OF THE COMMON COD

EXTRAIT DU JOURNAL DU CONSEIL INTERNATIONAL
POUR L'EXPLORATION DE LA MER
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The Scientific Name of the Common Cod

By

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U.S Fish and Wildlife Service, Washington, D.C.

Anyone using the voluminous literature on the common cod of the Atlantic Ocean soon becomes aware of inconsistency in the scientific nomenclature applied to this species. The purpose of this paper is to point out the causes of confusion and to indicate the proper name to be used under the International Code of Zoological Nomenclature.

In the 10th edition of the *Systema Naturae* (the starting point of formal zoological nomenclature), LINNAEUS described the genus *Gadus* on page 251. Following this description there are brief descriptions of 15 species which LINNAEUS placed in *Gadus*. At the top of page 252 is species number 2 — *callarias*, from European and Baltic seas. Directly beneath *callarias* on the same page is species number 3 — *morhua* (changed to *morrhua* by many later authors) from European seas. Both *G. callarias* and *G. morhua* were recognized as valid species until 1838 when FRIES (in FRIES, EKSTRÖM and SUNDEVALL, 1836–48) realized that the two names were applied to the same species. The name *G. callarias* had been used for young specimens and for the stunted population in the Baltic, while adults had been called *G. morhua*.

When two names apply to the same species, only one has priority, and it is this name alone which may validly be used for the species. The other name becomes a synonym, though as we shall see, it still remains available for use. In most instances of this nature there is little difficulty in determining priority. It is simply a matter of picking the first properly proposed name. In the case of the cod, however, the names *callarias* and *morhua* appear not only in the same volume, but on the very same page, and it is this fact which is the root of the difficulty.

The International Rules of Zoological Nomenclature state that when two species of the same date are united to form a single species, the name selected by the first reviser shall apply as the name of the species. It is recommended, however, that the name which occurs first in the publication be chosen if possible. FRIES was the first to synonymize *morhua* and *callarias* and is thus the first reviser. He chose the name *morrhua*, and although he did not apply the principle of page precedence, his choice is valid under the present rules.

It was, however, long ago realized that an additional measure of stability was necessary for the names of certain animals, and APSTEIN (1915) published a list of *nomina conservanda*, names which he felt should be conserved regardless of priority. Included in the *Pisces* section of his list was the genus *Gadus* and the species *morrhua*. Although the International Commission on Zoological Nomenclature (1922, Opinion 74) ruled they could not adopt APSTEIN's list *en bloc*, they were prepared to consider his suggestions one at a time, and later in the same year (Opinion 77) and with the recommendation of DAVID STARR JORDAN, the Commission followed APSTEIN's suggestions with regard to *Gadus* and other names and placed them on *The Official List of Generic Names in Zoology*. In 1956 the Commission (HEMMING, 1956) placed the name *morhua* LINNAEUS 1758, as published in the combination *Gadus morhua* on *The Official List of Specific Names in Zoology* (species no. 1079).

The Commission had previously decided (HEMMING, 1950) that once a specific name is placed on *The Official List of Specific Names in Zoology* this name is to be used in preference to any other name, even if it is found not to be available or not the oldest name for the species; unless the Commission directs otherwise.

There is no doubt, therefore, that *Gadus morhua* (note the use of LINNAEUS' original spelling of the specific name) is the proper scientific name of the cod. This conclusion would follow automatically by application of The International Rules of Zoological Nomenclature (as they stand when this is being written, May, 1959). The name is further reinforced by its inclusion in *The Official List of Specific Names in Zoology*, and should the rules change from "the rule of the first reviser" to "the rule of page precedence", the name *morhua* would still remain valid.

It is of interest to note that although the name *callarias* is a synonym of *morhua* in the genus *Gadus*, *callarias* is still available for use, and SVETOVIDOV (1948) has recognized the Baltic population of cod as the subspecies *Gadus morhua callarias*.

Acknowledgement

I thank Mr. JOHN P. WISE of the U. S. Fish and Wildlife Service for his kindness in commenting on the manuscript.

Summary

1. The original descriptions of *Gadus callarias* and *Gadus morhua* first appeared on the same page. When it was realized that the two names applied to the same species confusion arose as to which name should properly be used.

2. The International Commission on Zoological Nomenclature placed *Gadus* on *The Official List of Generic Names in Zoology* and *morhua*, as published in the combination *Gadus morhua*, on *The Official List of Specific Names in Zoology*. They also decided that once a specific name is placed on the *List* it is to be used in preference to any other name, even if it is found not to be available or not the oldest name for the species; unless the Commission otherwise directs. The scientific name of the common cod should therefore stand as *Gadus morhua* Linnaeus 1758.

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References

APSTEIN, C., 1915. "Nomina conservanda". Ges. naturforsch. Freunde, **5**: 119–93.

FRIES, B. F., EKSTRÖM, C. U., & SUNDEVALL, C. J., 1836–48. "Skandinaviens fiskar målade efter lefvande exemplar och ritade på sten af W. von Wright . . .". Stockholm.

HEMMING, FRANCIS, 1950 (editor). "The official record of proceedings of the International Commission on Zoological Nomenclature at its session held in Paris in July, 1948: Conclusions of ninth meeting (concluding portion)". Bull. Zool. Nomencl., **4**: 255–71.

HEMMING, FRANCIS, 1956 (editor). "Direction 57(a). Addition to *The Official List of Specific Names in Zoology* of the specific names of forty-seven species belonging to the classes Cyclostomata, Pisces, Amphibia and Reptilia, each of which is the type species of a genus, the name of which was placed on *The Official List of Generic Names in Zoology* in the period up to the end of 1936". Opinions and Declarations Rendered by The International Commission on Zoological Nomenclature, **1**, sect. D, pt. D. 18: 368–71.

International Commission on Zoological Nomenclature, 1922. "Opinions rendered by the International Commission on Zoological Nomenclature. Opinions 68 to 77." Smithsonian Misc. Coll., **73** (1): 1–73.

LINNAEUS, CAROLUS, 1758. "Systema Naturae, editio decima, reformata." Holmiae.

SVETOVIDOV, A. N., 1948. "Treskoobraznye". Zool. Inst. Akad. Nauk SSSR, N.S. 34, Fauna SSSR, Ryby: **2** (1): 1–351.

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A Field Observation of Mortality of Marine Fish Larvae Due to Warming

Georges Bank, one of the most productive shing grounds in the North Atlantic, provides a abitat for many populations of demersal fish, ncluding cod, haddock, whiting, and several pecies of flounders. The non-tidal circulation attern, being rotary, is favorable to maintaining hese populations on the bank. However, there exists ample evidence that from time to time a considerable amount of Georges Bank water is carried off the southern part of the bank in the surface layer of the relatively warm slope water band (Bigelow 1929, Walford 1938). Although the mechanism of these movements is not fully understood, such a southerly drift could be caused by winds or by the absorption of coastal water by the large frictionally driven eddies that develop from time to time along the northern edge of the Gulf Stream (Iselin 1939). Iselin speculated that this warm slope water is unfavorable to large numbers of animals living near the edge of the continental shelf.

The North Atlantic Fishery Investigations of the U. S. Fish and Wildlife Service have conducted surveys of Georges Bank and the surrounding area in 1953, 1955, 1956, and 1957 in order to measure the relative abundance of fish eggs and larvae and to relate their distribution and mortality to hydrographic conditions. We have observed that a drift off the southeast edge of Georges Bank occurred in each of these years. Four 2-week cruises were made each year during February, March, April, and May. Operations included continuous Hardy Plankton Recorder hauls at the surface and at 10 meters, bathythermograph lowerings and surface salinity samples, drift bottle releases, and egg samples taken with a one-meter net for hatching and identification. The track of a typical cruise is shown in Figure 1. The drift of bottles, eggs, and larvae revealed that, in general, the water movement from the area of maximum spawning on Georges Bank was southerly.

One of the interesting features of the hydrography of the Georges Bank area is the band of relatively warm slope water along the southern edge of the bank. This slope water band is characterized by contrasting tongues of coastal and

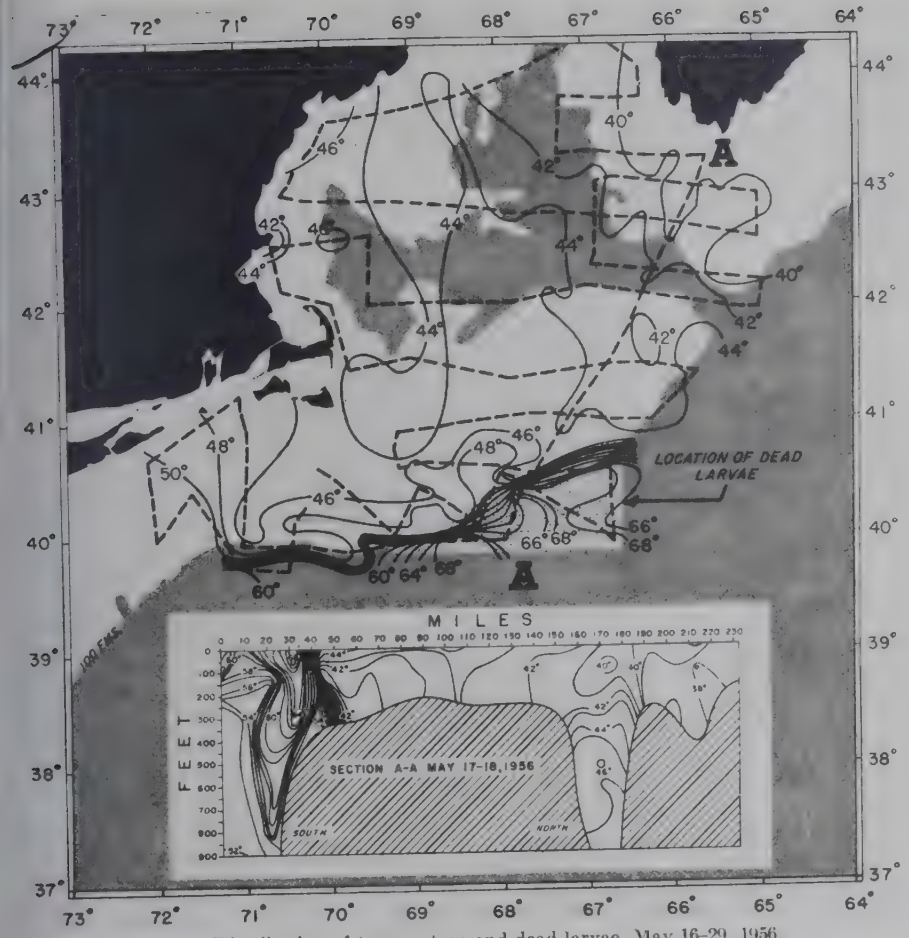

FIG. 1. Distribution of temperature and dead larvae, May 16–29, 1956.

Gulf Stream water. Here tropical plankton becomes mixed with coastal forms, and both drift slowly to the northeast, parallel to the Gulf Stream. In general, the northern boundary of this slope water band coincides with the 100-fathom contour line, but its position relative to Georges Bank, especially on the southeast part, varied during the 4 years of our surveys.

In May 1956 this slope water extended farther than usual over the southern edge of the bank (Fig. 1). Surface temperatures increased from 46°F to 68°F and surface salinities from 33‰ to 36‰ within a space of 10 miles. While we were cruising through this area, the temperature in our hatching jars (which are kept cool in a bath of running sea water) rose to 65°F, and most of the eggs died or aborted. No fish eggs, fish larvae, or invertebrates endemic to the Gulf of Maine-Georges Bank area were taken in the one-meter net surface hauls in this area, but juvenile stages of a number of tropical and oceanic species of fishes were caught, for example: mullett, *Mugil cephalus*; saurel, *Trachurus trachurus*; and lanternfish, *Myctophum humboltii*. The invertebrates in these samples were all tropical forms, the most numerous being the copepods, *Sapphirina gemma*, *Labidocera acutifrons*, *Undinula vulgaria*, and the euphausiid, *Euphausia krohnii*.

Later study of the Hardy Plankton Recorder gauzes revealed that certain sections contained many fish larvae in various stages of decomposition. These larvae were found in a particular area and only in the recorder towed at the 10-meter level. We first considered the possibility that there was a shortage of formalin in the storage tank of the recorder. However, only the

boreal forms were affected; all other plankters on the same sections were excellently preserved This indicates that the affected larvae must have died some time before capture. The majority of these dead larvae were yellowtail flounder (*Limanda ferruginea*), but there were some whiting (*Merluccius bilinearis*) and a few larvae that appeared to be blennies.

We took the dead larvae only in the slope water (Fig. 1). Only boreal forms had died in this zone, while tropical and sub-tropical forms had not. The eggs and larvae of the species normally resident on Georges Bank, which were maintained in hatching jars, died during the time that the vessel was passing through the slope water. The only condition that changed during this time was temperature of the circulating sea water in which the hatching jars were immersed for cooling. The water inside the jars was the same as that in which the eggs had been originally collected, and thus only the temperature could have varied. These facts are all consistent with the conclusion that the eggs and larvae died as a consequence of temperature above their limit of tolerance.

Several observers have associated mass mortalities of adult fishes with abnormally low temperatures (Storey and Gudger 1936, Gunter 1941, Verrill 1901). Copenhagen (1935) described a periodic mortality of fish in the Walvis region associated with a marked increase in surface temperature. However, he concluded that death was due either to anoxia, hydrogen sulphide poisoning, or poisonous plankton. Wiborg (1948) noted the occurrence of large numbers of dead cod larvae in the Lofoten area in April 1930, but unfortunately no hydrographic observations were taken at the time. As far as we know, the present observations are the only ones that have been made which indicate a mortality of marine fish larvae as a result of warming.

Precise knowledge of the thermal requirements of the egg, developing embryo, and larval stages is meager.[1] A species of fish can exist only within a certain range of temperature. However, this range is more or less adjustable, the extreme limits being precisely set by conditioning (acclimation). In general, coldwater fishes have a narrower range of thermal tolerance than warmwater fishes. It appears also that marine species are more sensitive to temperature change than freshwater species, and that the thermal requirements of the very early stages are more exacting than that of the adult.

Carefully controlled laboratory experiments show that (1) the rate of temperature change is an important factor in mortalities, for it can outstrip the ability of the fish to acclimate to the change or move to a more favorable environment, (2) the upper lethal temperature is remarkably precise within species when repeated for fish from similar acclimation temperatures, and (3) the upper lethal temperature is closer to the acclimated temperature than is the lower lethal temperature.

Conditions on the southern edge of Georges Bank during May 1956 were such that Georges Bank larvae could be subjected to a sudden increase in temperature. The dead larvae averaged 2.5 mm in length, which approximates the hatching size of both yellowtail and whiting. Judging from the incubation rates of both yellowtail and whiting eggs and from the direction and rate of surface drift in the area, these larvae were probably hatched from eggs spawned approximately 25 miles north during the end of April. The temperature of the water mass in which the eggs and larvae drifted and to which they had been acclimated was approximately 44°F. The age of the larvae and their rate of drift indicate that they were subjected to a rise in temperature of over 20° in a period of probably less than 24 hours. At that planktonic stage of development, their swimming powers are much too feeble to enable them to move to a more favorable environment.

The above observations on flounder and whiting are very important, as the larvae of other and more important species such as haddock, cod, hake, and cusk may meet a similar fate. The extreme fluctuations in year-class strength of haddock, for instance, may be related to such a mortality in the larval stages. The drift of concentrations of haddock eggs and larvae has frequently been followed by us from the spawning centers on the northern edge to the southern edge of Georges Bank and then lost. For example, a large concentration of haddock larvae situated just north of the warmwater area in May 1956 had disappeared by June. It now appears that the reason we have not found larvae in the slope water zone before is that they had died in the warm water, and their bodies had disintegrated or sunk below the depth sampled.

This is further evidence to support the theory that larval fish swept off the southern edge of Georges Bank into the slope water zone are lost to the fishery.

[1] For a summary of work done on the thermal requirements of fishes, see Brett (1956).

REFERENCES

Bigelow, H. G. 1929. Plankton of the offshore waters of the Gulf of Maine. Bull. U. S. Bur. Fish., **40**(2): 1–509.

Brett, J. R. 1956. Some principles in the thermal requirements of fishes. Quart. Rev. Biol., **31**(2): 75–87.

Copenhagen, W. J. 1953. The periodic mortality of fish in the Walvis region. A phenomenon within the Benguela Current. Invest. Rep. Fish. Mar. Biol. Surv. S. Africa, No. **14**: 1–35.

Gunter, G. P. 1941. Death of fishes due to cold on the Texas Coast, January 1940. Ecology, **22**: 203–208.

SELIN, C. O.'D. 1939. Some physical factors which may influence the productivity of New England's coastal waters. J. Mar. Res., **2**(1): 74–85.

STOREY, M., AND E. W. GUDGER. 1936. Mortality of fishes due to cold at Sanibel Island, Florida, 1886–1936. Ecology, **17**: 640–643.

VERRILL, A. E. 1901. A remarkable instance of the death of fishes at Bermuda in 1901. Amer. J. Sci. Ser. 4, **12**: 88–95.

WALFORD, L. A. 1938. Effects of currents on the distribution and survival of eggs and larvae of haddock (*Melanogrammus aeglefinus*) on Georges Bank. Bull. U. S. Bur. Fish., **49**(29): 1–73.

WIBORG, K. F. 1948. Investigations on cod larvae in the coastal waters of northern Norway. Fiskeridir. Skr. Havundersøk., **9**(3): 1–26.

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The Multiplane Kite-Otter as a Depressor for High-Speed Plankton Samplers

By

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Introduction

For some years we have been concerned with the problem of sampling larval and juvenile fish. This problem is complicated by the marked vertical and horizontal patchiness of postlarval and juvenile fish and their ability to avoid slow moving nets during daylight hours. The use of simultaneous high-speed, horizontal hauls with a number of nets on a single towing warp appears to be the most adequate method of sampling. To accomplish this, a depressor is needed that will allow us to sample down to at least 150 m at speeds up to 10 knots.

BARNES (1951) has described the use of the multiplane kite-otter for depth control of horizontal hauls. This gear is used extensively in mine sweeping work both as a diverter and as a depressor. BARNES' tows were made at slow speeds (4·5 knots), using relatively large diameter towing wire and a heavy depressor. At his suggestion (personal communication), we ran a series of depth calibration trials at speeds of 5, 7, and 10 knots using $\frac{1}{4}$ inch and $\frac{1}{2}$ inch towing wire with a 60 pound depressor. These data are presented here as the stability and diving characteristics of the multiplane kite-otter suggest its usefulness in many phases of oceanographic research.

Description of Multiplane Kite-Otter

There are three sizes of multiplane kite-otters used in mine sweeping operations, the dimensions, weight, and tow loads of which are given in Figure 1. The gear consists of a rectangular frame with four transverse curved plates set at an angle, the side plates of the frame being inclined to give lateral stability.

A detailed drawing of the 60 pound multiplane kite-otter used in the calibration trials is shown in Figure 2. When used as a depressor, the multiplane

U.S. NAVY NUMBER		#1	#4	#5
WEIGHT-LBS		500	180	60
APPROXIMATE TOW LOAD	5K	3800 LBS.	2600 LBS.	800 LBS
	7K			1800 LBS
	10K	14,000 LBS.	6000 LBS.	3000 LBS.
DIMENSIONS	A	5'-5 3/4"	3'-10 1/2"	3'-0-3/4"
	B	5'-2-1/2"	3'-8"	2'-10-1/4"
	C	9"	6-7/8"	5"
	D	4'-3-1/2"	3'-0 1/4"	2'-4"

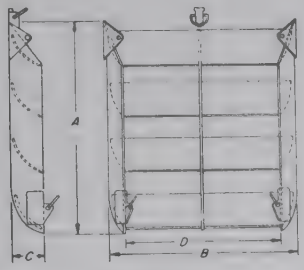

Figure 1. Dimensional sketch and specifications of U.S. Navy Type "O" multiplane kite-otter.

kite-otter is rigged with a three-point chain bridle. The lengths of the chain bridle legs are critical and must be correctly adjusted to keep the depressor towing directly astern of its tow point. The depressor will veer towards the shorter leg. Minor adjustments are made with a turnbuckle on one of the forward legs.

Methods

Two calibrations were necessary; one to determine the depressor depth at specified towing speeds with various wire sizes and wire scopes, and another to determine the wire profile with the depressor at specific depths. Two towing wire sizes were used; $\frac{1}{4}$ inch diameter, 7×19 galvanized preformed wire and $\frac{1}{2}$ inch diameter, 6×19 galvanized preformed wire. Wire vibration at speeds greater than 7 knots was considerable. Coil spring shock absorbers placed between the warp and the multiplane and at the end of the towing boom reduced this vibration considerably.

Depressor depth calibration

The depth calibration was accomplished as follows. With the ship stopped, a wire stop was secured just above the bridle and the depressor lowered to 10 m. After the ship had attained the desired towing speed, a bathythermograph was slid down the towing wire and the depressor retrieved at towing speed. The procedure was repeated at 10 m intervals until the length of wire out was more than twice the depressor depth. This was considered to be the maximum practical depressor depth as the amount of wire needed to obtain greater depths would be excessive. Depth calibration curves for $\frac{1}{4}$ inch wire at speeds of 5, 7, and 10 knots and for the $\frac{1}{2}$ inch wire at speeds of 7 and 10 knots are given in Figure 3.

Wire profile calibration

The wire profile for various depressor depths was determined from bathythermograph readings with the wire stop secured at successive 10 m intervals from the terminal end to the surface. For $\frac{1}{4}$ inch wire the depressor depths used were 50, 75, and 150 m at towing speeds of 5 and 7 knots and 50, 75, and 100 m

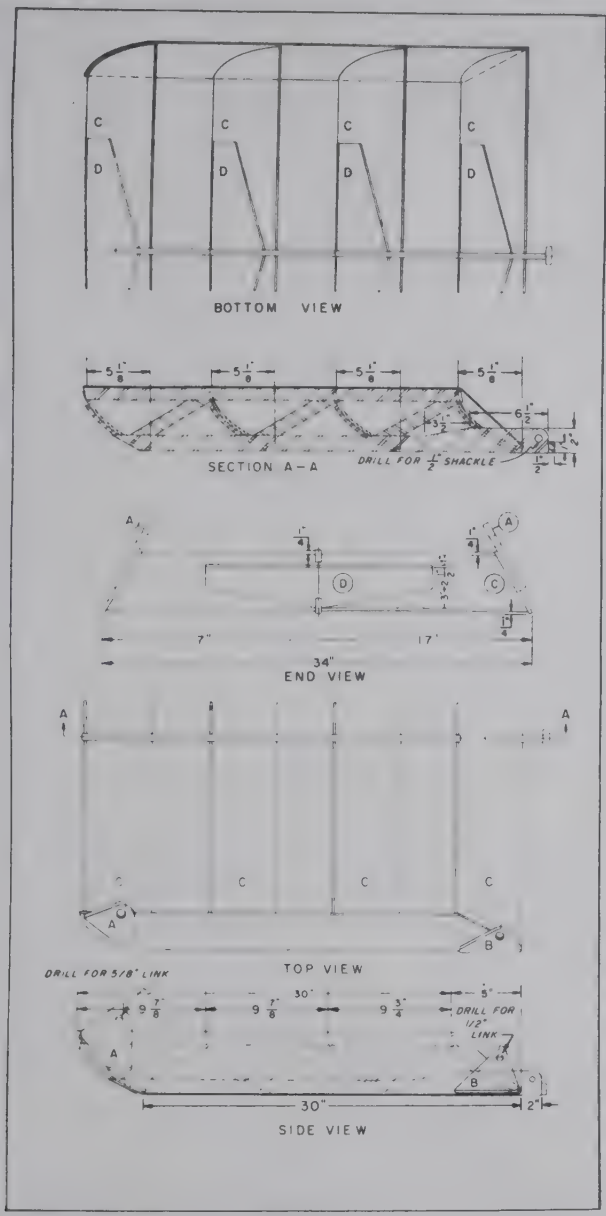

Figure 2A. Detail drawing of 60 pound multiplane kite-otter.

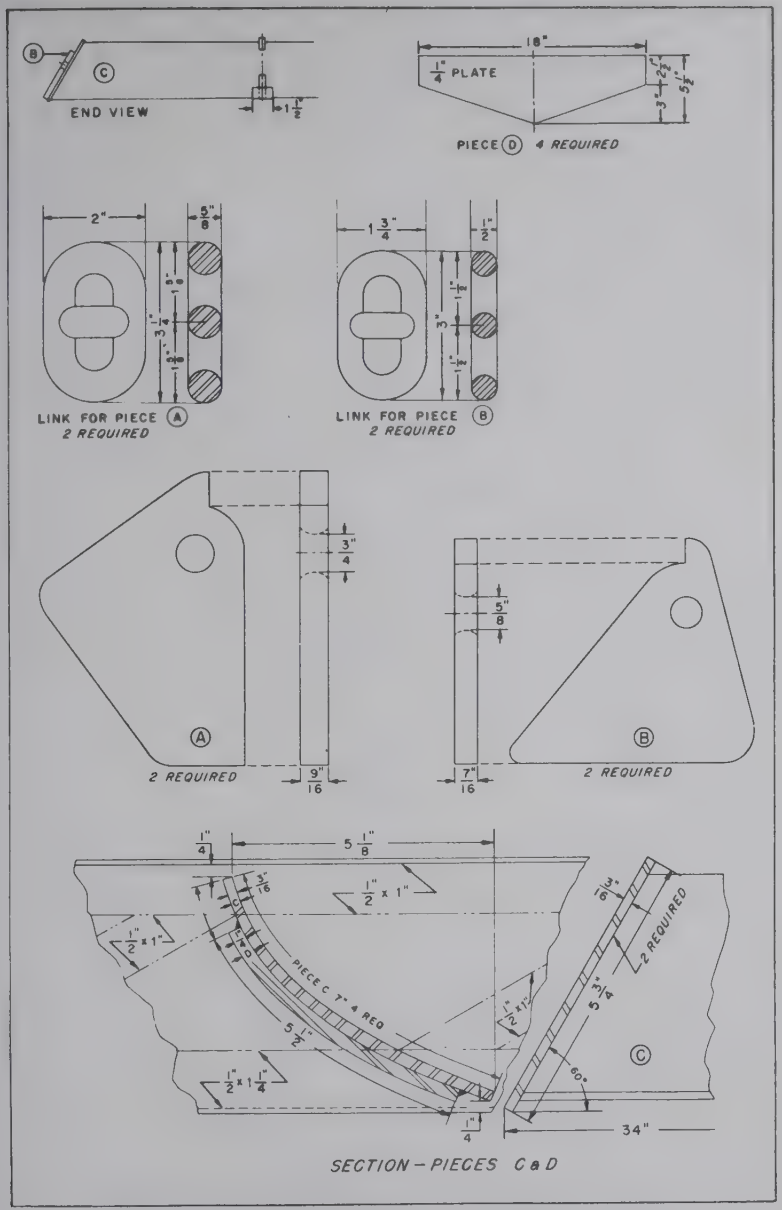

Figure 2B. Detail drawing of 60 pound multiplane kite-otter.

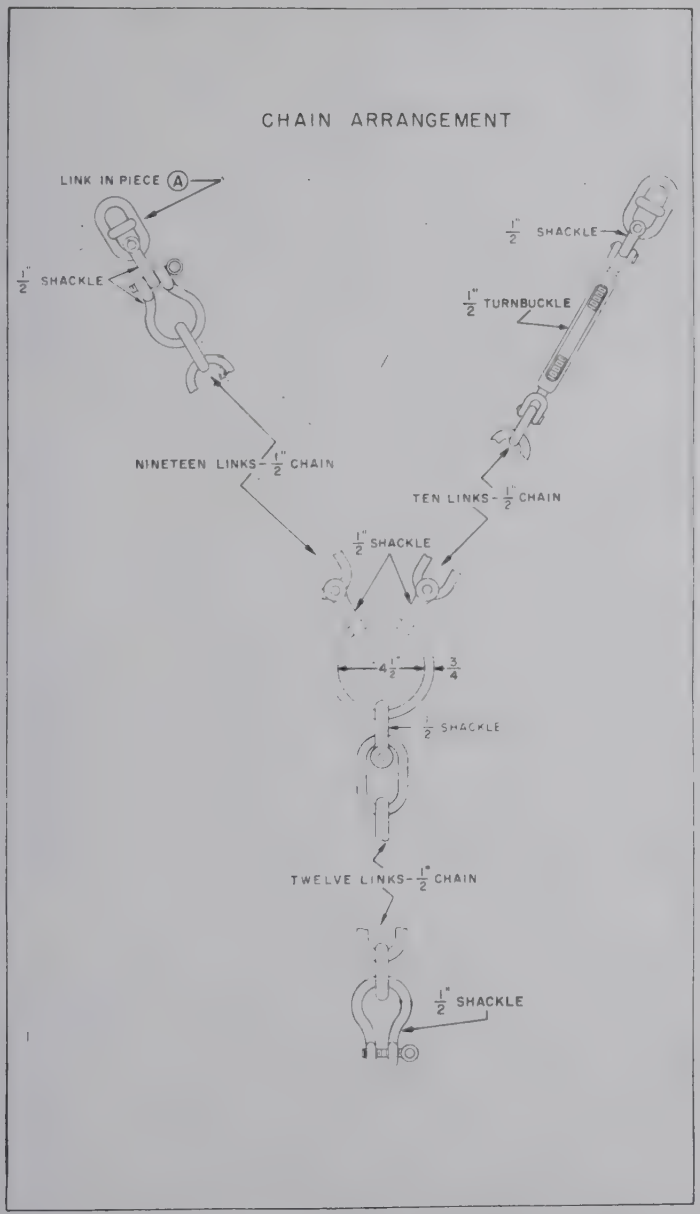

Figure 2C. Detail drawing of 60 pound multiplane kite-otter.

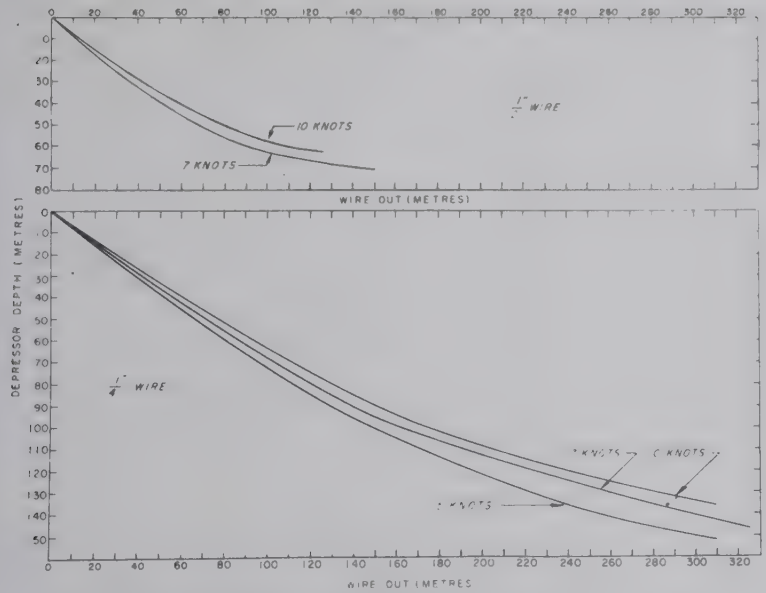

Figure 3. Relation of length of warp to depressor depth at various speeds.

at 10 knots. For $\frac{1}{2}$ inch wire the depressor depths were 40 and 60 m at a towing speed of 7 knots. These data, which are shown in Figure 4, have been plotted in terms of wire length (distance from terminal end) against depth rather than the distance of the depressor behind vessel against depth. Although such a plot does not show the actual curvature of the wire, it is more convenient for determining the proper spacing of samplers. For example, to sample at 60 m using $\frac{1}{4}$ inch wire at a towing speed of 7 knots and with the depressor at 150 m, the sampler should be positioned 142 m from the depressor. The total amount of wire out would be 343 m.

Results and Discussion

The multiplane kite-otter displays excellent diving and stability characteristics. The sensitivity of the turnbuckle adjustments for sheer is such that minute changes in towing angle are easily made. Adjustments for depth are not advisable. Once the final adjustments have been made, the sheer and diving characteristics remain constant so that the gear may be towed either from the side or from the stern of the vessel.

The maximum practical depressor depth varied more with wire size than with velocity. Because the relation of wire size to maximum depressor depth is inverse, it is desirable to use the smallest diameter wire practicable. It should be possible to use $^3/_{16}$ or $^7/_{32}$ inch diameter wire at speeds up to 7 knots and thereby increase the sampling depth appreciably.

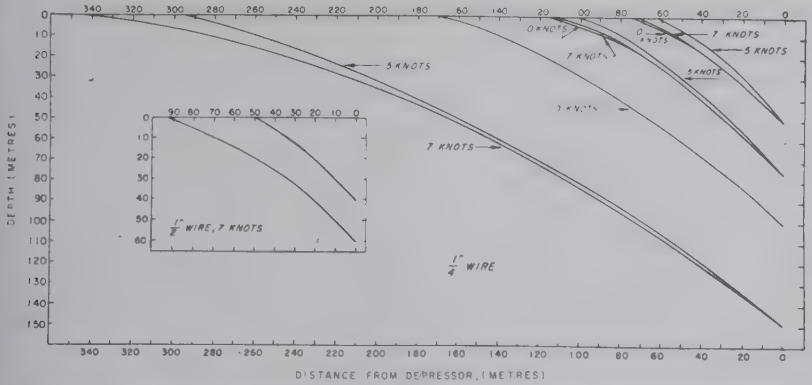

Figure 4. Curves for determining sampler spacing for $\frac{1}{4}$ inch wire with the depressor at 150 m (towing speed 5 and 7 knots), 100 m (towing speed 10 knots), 75 m (towing speed 5, 7, and 10 knots), and 50 m (towing speed 5, 7, and 10 knots) and for $\frac{1}{2}$ inch wire with the depressor at 40 and 60 m (towing speed 7 knots).

Because wire vibration makes the attachment of samplers difficult, it is more convenient to set out the gear and attach the samplers while stopped. The disadvantage of doing this is that the depth of water must be approximately twice that of the maximum desired sampling depth.

For most sampling, it appears that the 60 pound multiplane is the most practical size. We have, however, made up a half scale model weighing 25 pounds to be used with standard $^{3}/_{32}$ inch bathythermograph wire.

Because of the variations in ships' speeds and towing facilities, it would be advisable to undertake separate calibrations to meet specific needs.

The use of a small recording depth gauge that could be clipped onto the towing wire would greatly facilitate this work. A depth gauge would have the further advantage in that the wire profile could be calibrated with the samplers attached to the towing wire.

Summary

The multiplane kite-otter as a depressor is described. Depth and wire profile calibrations for a 60 pound multiplane and $\frac{1}{4}$ inch and $\frac{1}{2}$ inch towing wire at speeds of 5, 7, and 10 knots are presented. The diving and stability characteristics of the multiplane are discussed. Through the use of the multiplane kite-otter, it is possible to sample at high speed and at specific depths down to 150 m or more.

Reference

BARNES, H., 1951. "Horizontal plankton hauls". J. Cons. int. Explor. Mer, **17**: 133-39.

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A COMPARISON OF *TRACHINOTUS CAYENNENSIS* WITH *T. CAROLINUS* AND *T. PAITENSIS*

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A COMPARISON OF *TRACHINOTUS CAYENNENSIS* WITH *T. CAROLINUS* AND *T. PAITENSIS* [1]

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Trachinotus cayennensis Cuvier (Cuvier and Valenciennes, 1831: 417)[2] was described from a specimen two and one-half inches long, from Cayenne, French Guiana, and was distinguished from other *Trachinotus* indigenous to the Western North Atlantic by its high dorsal and anal fin soft-ray formulae and its low number of dorsal spines: D. V-I, 27; A. II-I, 26. Its other characters, as given by Jordan (1886: 531), are depth (2 in length) and a "very large eye." The holotype is the only specimen of the Cayenne pompano previously discussed in the literature.

Pompanos bearing high dorsal and anal fin-ray formulae taken off Venezuela and British Guiana by the U. S. Fish and Wildlife Service M/V *Oregon*, and off Surinam by the M/V *Coquette*, a vessel operated under contract to the Government of Surinam, were identified as *T. cayennensis*.

The only *Trachinotus* in the Western North Atlantic approaching *T. cayennensis* in fin-ray formulae is the common pompano, *T. carolinus* (Linnaeus). *T. paitensis* Cuvier (Cuvier and Valenciennes, 1831: 438),[2] of the Pacific coast of Central America and northern South America, also shows affinities to *T. cayennensis* (Meek and Goss, 1884: 129). Therefore *T. cayennensis* will be compared with these species. My data are shown in Table 1, and are supplemented by Hildebrand's (1946: 215-16) data for *T. paitensis*.

DEFINITIONS AND METHODS

All measurements were made with dividers and a rule. Those below 50 mm. were recorded to the nearest tenth mm., all above 50 mm., to the nearest half-millimeter.

Fin-ray counts: Roman numerals indicate spines; Arabic numerals indicate soft-rays. A dash indicates separation of the spinous from the soft fin, and a comma denotes a membrane

[1] Contribution Number 45 from the U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia.

[2] Authority according to Bailey, 1951.

connection or inclusion, as between the spine and the first soft-ray in all soft fins but the caudal.

Gill-raker counts: The first number indicates those rakers on the upper limb of the first gill arch; the number following the plus-sign represents those at the angle and on the lower limb. Rudiments are included where discernible, but tubercles at the ends of the arch are ignored.

Teeth: Each specimen was examined for dental development on premaxillary, vomer, palatines, tongue, and mandible.

Standard length, total length, head length, snout length and eye diameter were measured parallel to the longitudinal axis of the fish; depth was measured from the insertion of first anal spine to insertion of last dorsal spine. Snout to first dorsal spine, snout to first anal spine, and dorsal and anal base lengths are direct measurements. Dorsal and anal lobe lengths are from insertion of last spine to tip of lobe; paired fin lengths, from spine insertion to tip of fin. Caudal lobe length is the direct distance from anterior-most dorsal secondary caudal ray to tip of upper caudal lobe.

All specimen lengths are standard lengths unless otherwise stated.

Abbreviations are: USNM, United States National Museum; CNHM, Chicago National History Museum; UF, University of Florida Collections; *Ore.*, M/V *Oregon* specimens housed uncataloged in the collections of the Bureau of Commercial Fisheries, Biological Laboratory, Brunswick, Georgia (BLBG).

List of Specimens

Six specimens of *T. cayennensis* were examined: CNHM 64486, 193 mm., taken June 1-2, 1957, Lat. 06°20′ to 06°19′ N, Long. 54°54′ to 54°49′ W, *(Coquette)*; CNHM 64522-1 and -2, 306 and 299 mm., taken August 27, 1958, Lat. 09°29′ N, Long. 60°30′ W, (*Oregon* sta. 2214); USNM 159832, 205.5 mm., taken May 30, 1957, Lat. 06°23′ to 06°20′ N, Long. 54 47′ to 54°51′ W, (*Coquette* sta. 155); *Ore.* 2225, 199 mm., taken August 28, 1958, Lat. 08°32′ N, Long. 59°10′ W, (*Oregon* sta. 2225); *Ore.* 2214, 325 mm., taken August 27, 1958, Lat. 09°29′ N, Long. 60°30′ W, (*Oregon* sta. 2214).

One *T. paitensis*, USNM 77686, 285 mm., was examined from Lobos de Tierra, Peru.

Sixteen *T. carolinus*, 150.5 to 316 mm. were examined; thirteen (twelve BLBG, 150.5-209 mm., and one UF 5559, 166.5 mm.) from

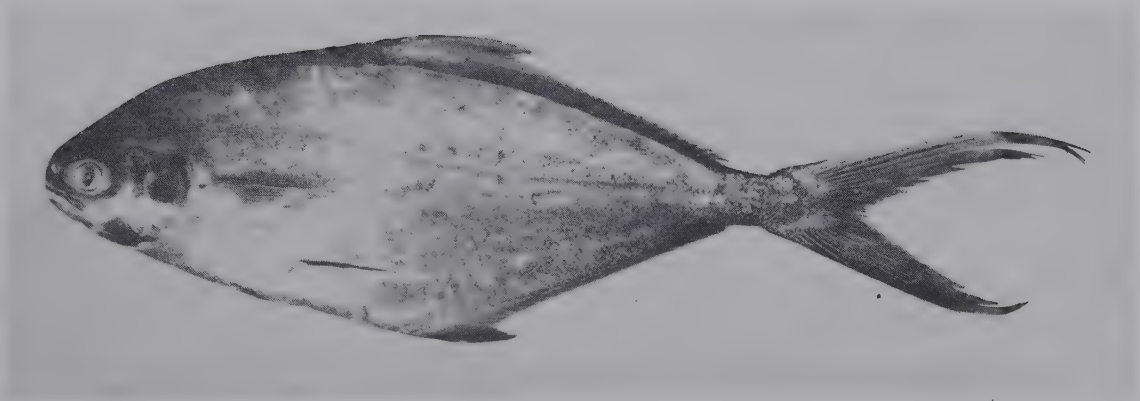

Figure 1.—*Trachinotus cayennensis* Cuvier, CNHM 64522-1, 306 mm. standard length.

off the coast of Brunswick, Georgia; two (BLBG, 262 and 316 mm.), from Fort Walton Beach, Florida; and one (UF uncatalogued, 283 mm.) from Kingston Harbour, Jamaica, British West Indies.

Description of the Species

Trachinotus cayennensis

Figure 1

One *T. cayennensis* has five dorsal spines; the remainder have six. Two have 26 dorsal soft-rays, one has 27, two have 28, and one has 29. One has 23 anal soft-rays; the remainder have 27. Meristic and morphometric ranges are given in Table 1.

These color notes are from two specimens (in formalin): *Ore.* 2214, 325 mm.—

Head: Dorsal aspect almost black with olivaceous shading above and behind eye. Preopercle and opercle with dark gray shading behind eye, grading into dingy yellow along posterior ventral margin. Branchiostegal region yellow-white. Snout and maxillary dusky.

Body: Back above lateral line gray-black from caudal base onto head, grading into yellow along lateral line. Belly and sides below lateral line yellow to yellow-white.

Soft dorsal: Light gray background with the leading edge, lobe tip, and ray-tips dusky.

Soft anal: Yellow-gray background on lobe; yellow on remainder. Leading edge, tip of lobe and ray-tips gray-black.

Caudal: Dusky-yellow with darker shadings along its perimeter and on the lobe tips.

Pectorals: Inner side gray-black at base and along first 9-10 soft-rays; remainder of rays white. Outer side dingy-yellow along base and onto first 5-6 rays. Leading edge of fin and tips of first 12 rays gray-black; remainder of tips white.

Pelvics: Creamy yellow.

Ore. 2225, 199 mm.—Similar to *Ore.* 2214 except for lack of yellow cast. The other specimens bear similar coloration, with the larger ones (299 and 306 mm.) possessing the yellow cast.

Trachinotus carolinus

Figure 2

Ginsburg (1952: 81, tables X and XI) examined 346 specimens of *T. carolinus* and reported that 51 had a dorsal spine count of 6

(V-I) while the remainder had 7 (VI-I). The range of dorsal soft-rays for 342 specimens was 23-27; 36 had 23 rays, 183 had 24, 110 had 25, 12 had 26 and one had 27. The maximum number of anal soft-rays for 346 specimens was 23; four specimens had 20 rays, 127 had 21, 188 had 22 and 27 had 23.[3] Of 16 *T. carolinus* I examined, two have 6 dorsal spines and the remainder have 7. Two have 23 dorsal soft-rays; eight have 24, four have 25, and two have 26. Two have 20 anal soft-rays; seven have 21; six have 22; and one has 23. Meristic and morphometric values are presented in Table 1.

Figure 2.—*Trachinotus carolinus* (Linnaeus), BLBG uncatalogued. 316 mm. standard length.

Trachinotus paitensis
Figure 3

The only specimen of *T. paitensis* I examined is one described and illustrated in Evermann and Radcliffe (1917: 62 and Pl. 6, fig. 1) as *T. paloma* Jordan and Starks, and in Hildebrand (1946: 216, fig. 48). My count of dorsal soft-rays is one more than that of Evermann and Radcliffe.

I find no information in the literature on the relationship of total length to standard length for *T. paitensis*. Therefore I rely on data given by Hildebrand (1941: 216): "The Mission furnished nine specimens, 75 to 270 mm. (57 to 197 mm. to base of caudal)

[3] *Trachinotus carolinus* (= *Gasterosteus carolinus* Linnaeus 1766: 490) was depicted as having an anal soft-ray formula of 27. However, Goode and Bean (1885: 203) stated that the holotype had 23 anal rays.

TABLE 1.—RANGES OF MERISTICS AND PROPORTIONAL MEASUREMENTS OF *T. CAYENNENSIS*, *T. CAROLINUS*, AND *T. PAITENSIS*. (THE SUPPLEMENTARY DATA ON *T. PAITENSIS* ARE FROM HILDEBRAND, 1946, pp. 215-216.)

	T. cayennensis (6 specimens)		*T. carolinus* (16 specimens)		*T. paitensis* (1 specimen)		*T. paitensis* (10 specimens from Hildebrand)	
	193-325 mm. Standard Length		150.5-316 mm. Standard Length		285 mm. Standard Length		57-285 mm. Standard Length	
Dorsal rays	IV to V-I, 26 to 29		V to VI-I, 23 to 26		VI-I, 26		VI-I, 24 to 27	
Anal rays	II-I, 23 to 27		II-I, 20 to 23		II-I, 23		II-I, 22 to 25	
Gill-rakers	6 to 7 + 13 to 15		2 to 6 + 7 to 10		4 + 11		3 to 4 + 8 to 10	
	In Standard Length	% of Standard Length	In Standard Length	% of Standard Length	In Standard Length	% of Standard Length	In Standard Length	% of Standard Length
Total length	0.6- 0.7	140.2-154.3	0.7- 0.8	126.9-134.9	—	—	0.7-0.8*	131.6-137.1*
Depth	2.3- 2.7	37.3- 42.7	2.0- 2.5	39.7- 50.3	2.6	38.8	2.2-2.5	—
Snout to first dorsal spine	2.4- 2.8	36.3- 41.7	2.2- 2.5	40.2- 45.8	2.6	39.1	—	—
Snout to first anal spine	2.0- 2.3	44.1- 50.3	1.7- 1.9	52.8- 59.8	2.0	50.5	—	—
Head length	4.1- 5.0	20.1- 24.7	3.5- 4.0	24.8- 28.8	4.3	23.2	3.5-4.25	—
Eye diameter	12.8-19.6	5.1- 7.8	12.5-17.8	5.6- 8.0	17.5	5.7	—	—
Dorsal base length	1.7- 1.8	56.2- 57.8	1.7- 1.9	53.8- 57.9	1.7	58.9	—	—
Anal base length	2.0- 2.2	45.6- 49.7	2.4- 2.7	37.3- 42.0	2.3	44.0	—	—
Dorsal lobe length	3.9- 5.2	19.4- 25.5	3.3- 4.2	23.8- 30.7	4.6	21.9	—	—
Anal lobe length	4.8- 5.5	18.3- 21.0	3.6- 4.3	23.1- 28.1	—	—	—	—
Caudal lobe length	1.8- 2.1	47.0- 56.9	2.3- 2.9	34.0- 43.7	—	—	—	—
Pectoral length	4.4- 5.4	18.6- 22.7	3.9- 4.8	20.7- 25.8	5.1	19.5	4.2-5.4	—
Pelvic length	10.0-13.9	7.2- 10.0	6.8- 9.7	10.3- 14.8	9.4	10.6	—	—
	In Head Length	% of Head Length	In Head Length	% of Head Length	In Head Length	% of Head Length	In Head Length	% of Head Length
Snout length	4.5- 6.1	16.4- 22.1	4.4- 6.3	15.9- 22.7	4.6	21.7	3.8-4.3	—
Eye diameter	3.2- 4.0	25.2- 31.7	3.6- 4.5	22.2- 27.9	4.0	24.7	3.7-5.6	—

* The determination of these data is explained on page 36.

long . . ." He also alludes to USNM 77686 by stating, "The large specimen secured by R. E. Coker, which was reported to be 380 mm. long (caudal now broken) . . ."

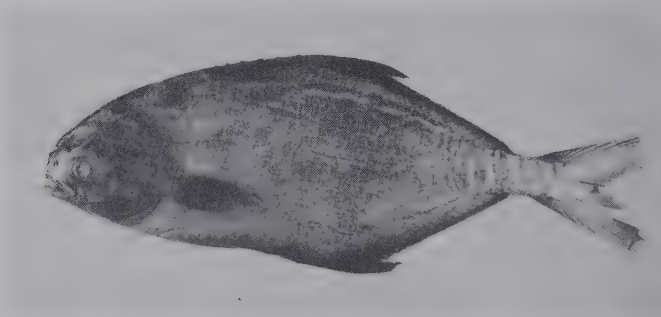

Figure 3.—*Trachinotus paitensis* Cuvier, USNM 77686, 285 mm. standard length.

With this information, and assuming that the minimum total length and the minimum standard length apply to the same fish and that the same is true for the maximum lengths, and by using the total and standard lengths for USNM 77686, limited ranges of proportions and percentages of total length to standard length for *T. paitensis* were determined and are included with Hildebrand's data in Table 1.

Comparisons

Table 1 shows that *T. cayennensis* differs from *T. carolinus* in the following characters: *T. cayennensis* possesses 5 or 6 dorsal spines (usually 6), 26 to 29 dorsal soft-rays and 23 to 27 anal soft-rays. *T. carolinus* possesses 6 or 7 dorsal spines (usually 7), 23 to 26 dorsal soft-rays and 20 to 23 anal soft-rays. *T. cayennensis* also has a higher gill-raker complement; proportionally greater total length, anal base length, and caudal lobe length; averages shallower depth, shorter snout to first dorsal spine distance, eye diameter, dorsal lobe length and pectoral length; and has considerably shorter head length, anal lobe length, pelvic length, and distance from snout to first anal spine.

T. cayennensis differs from *T. paitensis* in having a lower dorsal spine complement (*T. paitensis* has 7 spines), averaging higher

dorsal and anal soft-ray formulae (*T. paitensis* has 24 to 27 dorsal and 22 to 25 anal soft-rays), and having a much higher gill-raker complement. *T. cayennensis* also has proportionally greater total length, slightly greater anal base length and shorter pelvic length (Table 1).

T. cayennensis (193 to 325 mm.) shows considerably more dental development than *T. carolinus* and *T. paitensis*. Teeth are present on premaxillaries, mandible, vomer, and palatines of all *T. cayennensis*, and there are no teeth on the tongue. The smallest *T. carolinus* (150.5 mm.) has teeth on premaxillaries and mandible only; three of the four next larger *T. carolinus* (157-165.5 mm.) have teeth on the mandible only; and all larger specimens are toothless. *T. paitensis* (285 mm.) has teeth on the mandible only.

Acknowledgments

I wish to acknowledge the generous assistance of the following individuals: Harvey R. Bullis, U. S. Fish and Wildlife Service, provided the *T. cayennensis* that initiated this study; Leonard P. Schultz made available U. S. National Museum materials; Loren P. Woods furnished Chicago Natural History Museum specimens; David K. Caldwell, U. S. Fish and Wildlife Service, supplied University of Florida material and offered many helpful suggestions in the preparation of the manuscript; Frederick H. Berry, U. S. Fish and Wildlife Service, obtained the material in the Biological Laboratory, Brunswick, Georgia, collectons, and gave much constructive advice; William W. Anderson and Jack W. Gehringer, U. S. Fish and Wildlife Service, offered many helpful suggestions and critically reviewed the manuscript.

Literature Cited

BAILEY, REEVE M.

1951. The authorship of names proposed in Cuvier and Valenciennes' "Histoire Naturelle des Poissons." *Copeia*, 1951 (3): 249-251.

CUVIER, G., and A. VALENCIENNES

1831. *Histoire Naturelle des Poissons.* Paris: F. G. Levrault, 8: iv + 470, 36 pls.

EVERMANN, BARTON WARREN, and LEWIS RADCLIFFE

1917. The fishes of the west coast of Peru and the Titicaca Basin. *Bull. U. S. Natl. Mus.*, 95: xi + 166, 14 pls.

GINSBURG, ISAAC
1952. Fishes of the family Carangidae of the northern Gulf of Mexico and three related species. *Pub. Inst. Mar. Sci., Univ. Texas,* 2(2): 47-117, 7 pls.

GOODE, GEORGE BROWN and TARLETON H. BEAN
1885. On the American fishes in the Linnaean collection. *Proc. U. S. Natl. Mus.,* 8: 193-208.

HILDEBRAND, SAMUEL F.
1946. A descriptive catalog of the shore fishes of Peru. *Bull. U. S. Natl. Mus.,* 189: xi + 530 pp., 95 figs.

JORDAN, DAVID STARR
1886. Notes on typical specimens of fishes described by Cuvier and Valenciennes and preserved in the Musée d'Histoire Naturelle in Paris. *Proc. U. S. Natl. Mus.,* 9: 525-546.

LINNEAUS, CARL von
1766. *Systema Naturae.* Editio duo decima, Stockholm: Laurentii Salvii, Vol. 1, pt. 1, 532 pp.

MEEK, SETH E., and DAVID K. GOSS
1885. A review of the American species of the genus *Trachynotus. Proc. Acad. Nat. Sci. Phila.* (for 1884), 36: 121-129.

OCCURRENCE OF EXTREMELY SMALL OVIGEROUS CRABS (*CALLINECTES* SP.) IN COASTAL NORTH CAROLINA

By
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OCCURRENCE OF EXTREMELY SMALL OVIGEROUS CRABS (*CALLINECTES* SP.) IN COASTAL NORTH CAROLINA

The smallest adult female blue crab (*Callinectes sapidus* Rathbun) reported in the literature was 80 mm wide and 35 mm long (Hay and Shore 1918). On August 6, 1958 two smaller adult female crabs (*Callinectes* sp.), in an ovigerous condition, were caught by a shrimp trawl approximately one mile south of the entrance to Silver Lake, Ocracoke Island, North Carolina (Table I). They were taken over a sand, mud, and seaweed bottom in water ranging from 4 to 15 feet in depth. Surface water temperature was 26.8° C and surface salinity 21 $^{0}/_{00}$.

TABLE I. Measurements of small ovigerous crabs, *Callinectes sapidus?* taken in 1958

Measurement	Crabs caught off Ocracoke Island		Crab caught off Radio Island
	A	B	C
Length of carapace mm	23.3	24.1	22.2
Width of carapace mm	55.0	55.0	52.3
Fronto-orbital width mm	19.4	20.8	19.1

The frontal outline and other external characteristics of these adult crabs, except for their small size, resemble *Callinectes sapidus* Rathbun. W. A. Van Engel of the Virginia Fisheries Laboratory, and F. A. Chace, Jr. of the United States National Museum examined these crabs, and both agree that they appear to be *C. sapidus* Rathbun. D. G. Cargo, Maryland Department of Research and Education, also examined the crabs and stated that ". . . of the presently described species (Rathbun 1930), these most closely correspond to the published descriptions of *Callinectes sapidus.*" Mr. Cargo, who is familiar with measurements taken on 14,000 adult female blue crabs—the smallest of which was 36 mm in length, further stated ". . . it is difficult to reconcile that an adult of this species could develop at a length of 24 mm."

Another extremely small ovigerous crab was collec on October 23, 1958 by C. M. and T. G. Roberts of U. S. Radiobiological Laboratory, Beaufort, North Ca lina (Table I). This crab, caught in a haul seine the eastward shore of Radio Island, Morehead Ci North Carolina, also resembled *C. sapidus* and v identical in frontal outline and other characteristics w the 2 caught off Ocracoke Island.

The measurements of the 3 crabs reported herein w made in a manner prescribed by Rathbun (1930). Ra bun (1896), in describing the blue crab, stated that ad females normally vary from 5 to 7 inches (127 to millimeters) in width.

If the 3 specimens of ovigerous crabs described abo are *C. sapidus* Rathbun, which is the critical opinion Messrs. Van Engle, Chace, and Cargo, then they are t smallest adult females of this species so reported. It not known whether these dwarf forms of *C. sapid* normally occur in the areas in which they were collecte or whether they are the result of genetical or enviro mental factors influencing growth and thereby causi dwarfism.

REFERENCES

Hay, W. P. and C. A. Shore. 1918. The Decap Crustaceans of Beaufort, N. C., and the surroundi region. Bull. U. S. Bur. Fish. (1915-16), 35: 36 476.

Rathbun, M. J. 1896. The genus Callinectes. Pro U. S. Nat. Mus. (1895) 18: 349-375.

———. 1930. The cancroid crabs of America of t families Euryalidae, Portunidae, Atelecyclidae, Ca cridae, and Xanthidae. U. S. Nat. Mus. Bull. 152.

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LEPTOCEPHALUS OF THE ATLANTIC TARPON, *MEGALOPS ATLANTICUS* VALENCIENNES, FROM OFFSHORE WATERS

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Plankton samples were collected as part of the routine biological observations made during cruises of the M/V *Theodore N. Gill* off the south Atlantic coast of the United States during the years 1953 and 1954. The cruises constituted the initial or collecting phase of the U. S. Fish and Wildlife Service's biological, chemical, and oceanographic inventory of the waters from Cape Hatteras, North Carolina to the Straits of Florida from the coast out to beyond the approximate axis of the Gulf Stream. During the examination of fish larvae taken in the plankton tows, in particular the search for leptocephalid larvae of the ten-pounder, *Elops saurus* Linnaeus, one leptocephalid form was found that resembled the ten-pounder larvae in general form (ribbonlike with flattened, triangular head and forked caudal fin), but differed in numbers of dorsal and anal rays (ray bases), and body myomeres. This leptocephalus, 18.0 mm. in standard length, was taken in an oblique tow (65 meters to surface) with a half-meter plankton net at 1225-1249 hours on August 5, 1953, at Regular Station 40 of *T. N. Gill* cruise 3, 31°30′ N. lat., 78°42′ W. long., about 150 miles east and slightly north of Brunswick, Georgia, and well out in the Gulf Stream.

The unusual larval development of the tarpon, the ten-pounder, and the bonefish *Albula vulpes* (Linnaeus), requires special terminology to distinguish the developmental stages since there are two periods of length increase separated by a period of length decrease (the beginning of metamorphosis). I have restricted the term *leptocephalus* to a larva in its initial stage of length increase, up to the size at which shrinking begins; while the term *metamorphic larva* is suggested for a larva undergoing shrinking, during metamorphosis, and subsequent length increase to the juvenile stage (Gehringer, *in press*).

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series of metamorphosing *M. cyprinoides* in which the earliest stage larva, about 20 mm. S. L., has a well-developed air bladder. I believe my specimen to be in the initial stage of length increase because it does not exhibit the development evidenced in these various larvae (metamorphic larvae by my definition).

The Marine Laboratory of the University of Miami collected eggs suspected of being those of the Atlantic tarpon, *M. atlanticus*, and maintained them through hatching and to larvae of 3.45 mm. standard length, or about 48 hours beyond time of hatching, before they died (Ellis, 1956)—duplicating earlier experiments by Breder (1944), whose larvae reached 2.9 mm. at 43 hours, but which shrunk to 1.9 mm. at 72 hours before dying (shrinkage is not explained). There have been no successful attempts to carry the egg through to a leptocephalus identifiable as that of the tarpon. Ellis (1956) speculated that after hatching the tarpon leptocephalus may move offshore with the currents and spend its early life as an open-ocean planktonic form. The leptocephalus taken on the *Gill* cruise lends evidence to this speculation.

Description of Preserved Specimen

Figure 1

Head: Triangular in dorsal aspect and compressed dorso-ventrally, wider than body, translucent with brain clearly visible; nostrils, shallow depressions; eyes large and oval; teeth, one fang-like tooth anteriorly on each side of upper jaw larger than remaining 4 in upper jaw and 5 in lower jaw.

Body: Uniformly thin, deep (ribbonlike), translucent with 55-57 body myomeres easily discernible with transmitted light (last few in caudal are indistinct); central nerve cord visible; vertebrae developing in caudal portion; digestive tract a tube appended to ventral margin of myomeres, anus opposite 41st myomere; air bladder a slight dorsal swelling in digestive tract at 23rd myomere; kidney dorsal to digestive tract at 35th to 41st myomeres.

Fins: Dorsal and anal finfold frayed with only ray bases formed, 12 dorsal and 21 anal, dorsal ray bases opposite 39th to 42nd myomeres and anal bases opposite 42nd to 48th myomeres, predorsal finfold small (fig. 1); caudal fin with 10 + 9 principal rays and 1 ventral secondary ray (none branched), hypural plates discernible

with transmitted light, urostyle prominent; some finfold at caudal peduncle, but no preanal finfold as is found in *Elops saurus* (Gehringer, *in press*); pectoral fin a rounded bud with no rays developed; no pelvic fin.

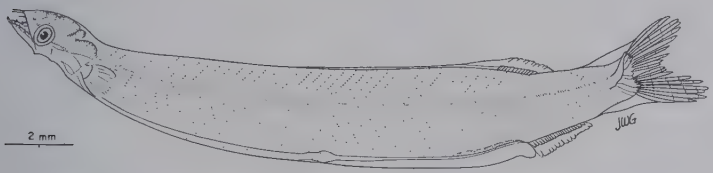

Figure 1. Leptocephalus of the Atlantic tarpon, *Megalops atlanticus* Valenciennes, 18.0 mm. in standard length.

Selected measurements: All measurements were made with aid of binocular microscope and micrometer eyepiece: Standard length, 18.0 mm.; total length, 19.7 mm.; head length, 2.40 mm.; length of lower jaw, 1.43 mm.; eye diameter (horizontal), 0.38 mm.; distance from snout to dorsal fin (anterior ray base), 13.1 mm.; distance from snout to anal fin (anterior ray base), 13.8 mm.; depth of head (at angle of jaw), 1.18 mm.; body depth at pectoral fin, 1.27 mm.; body depth at air bladder, 2.54 mm.; length of anal base, 1.56 mm.; length of dorsal base, 1.14 mm.

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Literature Cited

ALIKUNHI, K. H., and S. NAGARAJA RAO.
1951. Notes on the metamorphosis of *Elops saurus* Linn. and *Megalops cyprinoides* (Broussonet) with observations on their growth. *Journal of the Zoological Society of India*, 3(1): 99-109, 2 text-figs.

ANONYMOUS
1955. Opening the door to discovery. *Bulletin of the International Oceanographic Foundation*, 1(3): 44-47.

BAILEY, REEVE M.
1951. The authorship of names proposed in Cuvier and Valenciennes' Histoire Naturelle des Poissons. *Copeia*, 1951(3): 249-251.

BAL, D. V., and L. B. PRADHAN.
1947. Investigation of fish eggs and larvae from Bombay waters; Third Progress Report; 1946-47. *Department of Zoology Royal Institute of Science*, Bombay. [not seen]

BREDER, C. M., JR.
1944. Materials for the study of the life history of *Tarpon atlanticus*. *Zoologica*, 29(19): 217-252, text-figs. 1-9.

CHIDAMBARAM, K., and M. DEVIDAS MENON.
1948. Notes on the development of *Megalops cyprinoides* and *Hemirhamphus georgii*. *Proceedings of the Zoological Society of London*, 117: 756-763, figs. 1-9.

DELSMAN, H. C.
1926. Fish eggs and larvae from the Java Sea (10. On a few larvae of empang fishes). *Treubia*, 8(3-4): 400-412, 17 figs.

ELLIS, ROBERT W.
1956. Tarpon cooperative research program progress report. Report to Florida State Board of Conservation by The Marine Laboratory, University of Miami, July, 1956, 13 pp. (mimeographed).

GEHRINGER, JACK W.
In press
Early development and metamorphosis of the ten-pounder, *Elops saurus* Linnaeus. U. S. Fish and Wildlife Service, *Fishery Bulletin*.

HARRINGTON, ROBERT W., JR.
1958. Morphometry and ecology of small tarpon, *Megalops atlantica* Valenciennes from the transitional stage through onset of scale formation. *Copeia*, 1958(1): 1-10, 5 figs., 2 pls.

HILDEBRAND, SAMUEL F.
1934. The capture of a young tarpon, *Tarpon atlanticus*, at Beaufort, North Carolina. *Copeia*, 1934(1): 45-46.
1943. Notes on the affinity, anatomy, and development of *Elops saurus* Linnaeus. *Jour. Wash. Acad. Sci.*, 33(3): 90-94, figs. 1-3.

HOLSTVOOGD, C.
1936. The development of the mesonephros in some teleosts. Proefschrift, Universiteit van Amsterdam. Meijer's Boek—en Handelsdrukkerij—Wormerveer, xvi+98 pp., 14 figs., 35 photographs.

VAN KAMPEN, P. N.
1908. Die larve von *Megalops cyprinoides* Brouss. *Bulletin du Department De l'Agriculture aux Indees Neerlandaises*, No. 20, pp. 10-12, 1 fig.
1928. The larva of the East Indian tarpon, *Megalops cyprinoides* Brouss. [Translation of 1908 publication, from *Beneath Tropical Seas* by William Beebe, G. P. Putnam's Sons, New York-London, pp. 228-229]

Franklin Gull in the Central Pacific.—While on an oceanographic and tuna-fishing cruise to the Marquesas Islands in May and June of 1958, the author sighted a pair of Franklin Gulls (*Larus pipixcan*) at Taiohae Bay, Nuku Hiva. The birds were first seen on May 15 and remained in Taiohae Bay until May 25 when they disappeared. Both birds were black-headed, in typical nuptial plumage; the distinctive black markings across the white tips of the wings were clearly observed. In a search of the available literature on birds of the Marquesas, we failed to find any mention of the Franklin Gull.

Two representatives of this species were also sighted in Hawaiian waters at about the same time. On May 30, 1958, Henry Hasegawa collected a specimen of Franklin Gull about 2 miles off Kekaha Light, Kauai. The gull was in company with a flock of terns and shearwaters which were working over a school of skipjack tuna. The author examined the specimen after it had been mounted by a local taxidermist and compared it with the figures and description provided by Dwight (Bull. Amer. Mus. Nat. Hist., 52, 1925). This bird was also in typical breeding plumage and even in the preserved state showed a slight rosy "bloom" on the breast. This coloration was reported to be considerably more prominent on the freshly collected specimen. On June 14, Mr. Hasegawa saw a second Franklin Gull in West Loch of Pearl Harbor, Oahu; this bird was not collected, however.

Mr. Hasegawa is an engineer on a tuna fishing vessel and is thoroughly familiar with the common sea birds of the Hawaiian area. He collected the gull because he had never seen a bird of this type before in Hawaii and realized that its presence here was worth verifying.

The only other recent sighting of a Franklin Gull in Hawaii was that by John W. Slipp who saw and photographed a single specimen near Barber's Point, Oahu, on May 16, 1953 (Elepaio 14(1), 1953:7). The A.O.U. Check-list (1957:227) indicates that the Franklin Gull is "Accidental in Hawaii (Maui), ..." This statement was probably based on W. A. Bryan's list of Hawaiian birds in the St. Louis College collection (Auk, 18, 1901:382–387) which describes a specimen in immature plumage, most likely taken on Maui but with collection data lacking. The author has been an observer of Hawaiian birdlife for nine years but has not sighted the species in Hawaii in that period.—Joseph E. King, *Honolulu, Hawaii, November 20, 1958.*

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ylostoma—an Enemy of ve Larvae

ract. In laboratory cultures, where of such bivalves as oysters and were kept together with large cili- the family Condylostomidae, the were seen ingesting the larvae. A *Condylostoma* could contain as as six larvae. Related species may many bivalve larvae in nature.

ause of their small size and long existence, larvae of such bivalves ers, clams, and mussels are eaten ny holoplanktonic animals ranging protozoans to fishes. Thorson (*1*), excellent account of reproduction rval development of Danish ma- nvertebrates, offers a brief review enemies of pelagic larvae. His , however, shows that, with the ion of the dinoflagellate *Noctiluca,* rotozoa subsist, in part, on lamel- ch larvae. My co-workers and I therefore, that our observations of *lostoma* sp., a heterotrich of the Condylostomidae, feeding on lar- the hard clam, *Venus mercenaria,* e American oyster, *Crassostrea vir-* are of biological interest and, per- practical significance.

discovery that *Condylostoma* on lamellibranch larvae was made inter when populations of an un- ied species of *Condylostoma* estab- themselves in several large glass serving as intermediate reservoirs xed phytoplankton cultures which fed routinely to the oysters and maintained in special trays during nter (*2*). The temperature in these usually ranged between 16.0° and C, and the salinity of the water was lly near 27.0 parts per thousand. dual *Condylostoma* varied in size approximately 400 to 900 μ when ded. In some instances their peri-

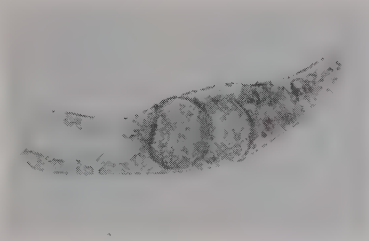

Fig. 1. *Condylostoma* with two ingested larvae of *Venus mercenaria* (*3*). (About × 100)

stomes reached a length of 225 to 250 μ. They were apparently well adapted to the conditions under which they existed, because small groups, when placed in 500-cm³ beakers to which a considerable quantity of mixed phytoplankton was added, lived for 2 to 3 months.

The first observation that *Condylostoma* ingests lamellibranch larvae was made when some of the plankton containing these ciliates was fed to cultures of young larvae of the common clam, *Venus mercenaria.* While examining the larvae, we noticed that some were guided into the gullet by the undulating membrane in the peristome of *Condylostoma* and that they were finally engulfed by the ciliates.

The number of larvae that can be ingested by a single *Condylostoma* depends upon the size of the predator and the size of the larvae. In one individual, measuring 661 μ and having a peristome approximately 178 μ long, six larvae could be seen. In smaller individuals, such as the one shown in Fig. 1, only one or two larvae were found. Progressive digestion of the soft parts of the ingested larvae was indicated by the changes occurring in their appearance. Usually the ones ingested first were distinctly paler in color than those ingested later, probably because of the disappearance of the fleshy part. Regardless of the frequent and prolonged observations on feeding *Condylostoma,* ejection of the shells of the larvae has never been observed. It is possible, therefore, that the shells also are eventually entirely digested within the body of the predator.

Perhaps what we saw taking place under laboratory conditions occurred because of the crowding of *Condylostoma* and lamellibranch larvae. It would probably seldom take place in nature, largely because *Condylostoma* is not very common on oyster bottoms or in the masses of water over the oyster beds where larvae are found during the summer. Our observations suggest, however, that members of another closely related family, Folliculinidae, may present a danger. These ciliates are at times extremely numerous in oyster-producing areas such as Chesapeake Bay, where, on occasion, they virtually cover the oyster shells planted as cultch to obtain a new generation of oysters. Some of these may be capable of engulfing oyster larvae, especially when the latter descend to the bottom to undergo metamorphosis into juvenile oysters. The same may be true of other members of the suborder Heterotrichina in which the peristomes and gullets may expand to become large enough for the passage of lamellibranch larvae. Such studies suggest many interesting possibilities.

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References and Notes

1. G. Thorson, *Medd. Kommissionen For Danmarks Fiskeriog Havundersogelser Ser.: Plankton* 4, 1 (1946).
2. V. L. Loosanoff, *Ecology* 32, 748 (1951).
3. I wish to express my thanks to Mrs. Matoira Chanley for taking the photograph.

7 November 1958

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THE SIZE AND SHAPE OF METAMORPHOSING LARVAE OF VENUS (MERCENARIA) MERCENARIA GROWN AT DIFFERENT TEMPERATURES

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THE SIZE AND SHAPE OF METAMORPHOSING LARVAE OF VENUS (MERCENARIA) MERCENARIA GROWN AT DIFFERENT TEMPERATURES

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Among the characters to be employed for identification of lamellibranch larvae, their size at metamorphosis has been suggested by some workers (Lebour, 1938). Other students have maintained, however, that since there may be correlations between size and environmental factors, the size at metamorphosis cannot be used as a criterion for recognition of larvae. Sullivan (1948) thought that this was confirmed for mature larvae of *Mya arenaria* in Canadian waters, which she observed to metamorphose in Malpeque Bay upon reaching a length of 250 microns, as compared with a length of 415 microns reported by Stafford (1912) for larvae of the same clam in the St. Andrews region.

According to Sullivan the difference in size at setting was probably the result of the difference in the summer water temperature at these two places because larvae developing at the lower temperature (St. Andrews) needed to reach a larger size before metamorphosing. This opinion is, indirectly, in agreement with that of Erdmann (1934), who thought that the size of larvae of the European oyster, *Ostrea edulis,* at the time of swarming was regulated by the temperature at which the larvae developed.

So far, no one has offered a definite explanation as to why lamellibranch larvae should reach a larger size if grown in colder water. It seems, however, that this opinion was formed because it is widely believed that, "In many instances, and perhaps as a general rule, the size that an animal attains is greater when it is reared at low temperature" (Coker, 1947, p. 102). Furthermore, since it is known that large individuals of the same species have a relatively smaller surface area than do small ones, the larger size may be considered as an adaptation to an increase in the viscosity of the water which accompanies a decrease in temperature. Examples to support this assumption can be found in numerous papers, including those of Murray and Hjort (1912), and many students of Radiolaria, copepods and certain other forms (Hedgpeth, 1957). Kofoid (1930), for instance, reported that marine protozoa living in cold water grow to much larger sizes than do their relatives existing at higher temperatures.

Aquatic biology also offers many instances in which organisms of the same species grown at different temperatures may show a somewhat different shape. The phenomenon of cyclomorphosis, reviewed by Brooks (1946), is an example. In lamellibranch larvae, of course, no radical changes in structure, as observed in Daphnia populations, can be anticipated. Yet, it has been reported (Jørgensen, 1946, p. 296) that at least in some lamellibranchs, such as *Venus gallina,* "the larval outline varies from almost square to circular." According to the same author

the veligers of the common mussel, *Mytilus edulis,* of Danish waters also show a remarkable variability in their shape. The water temperature during development can again be suspected as a factor affecting the shape of the larva.

During the past few years larvae of approximately 20 species of lamellibranchs have been successfully cultured from fertilized egg through metamorphosis by members of our laboratory (Loosanoff, 1954). The data collected during these studies will soon permit us to offer reliable material for recognizing larvae of the species with which we have been working. It will include photomicrographs of the larvae and length-width measurements of their shells from early straight hinge stage until metamorphosis. However, before offering these criteria, it was deemed necessary to ascertain the following possibilities, which could reflect on the reliability of our material:

1) We wanted to know whether, as is suggested by some students, individuals of larval populations grown at relatively low temperatures reach a larger size before metamorphosing than do larvae grown in warmer water. If this is true, special corrections, perhaps as formulae, should be offered to show the relationship between average size at setting and water temperature.

2) Since one of the criteria for recognizing a larva nearing metamorphosis is its dimensions, *i.e.,* length and width, it was necessary to determine whether the length-width ratio is relatively constant or if it changes in conformance with the temperature of the water in which larvae develop.

The questions posed above could be answered only on the basis of well-controlled experiments in which the water temperature was the only factor varied. Obviously, because of the time and efforts required, it would have been difficult to conduct such experiments with larvae of all 20 species of lamellibranchs with which we were working. We decided, therefore, to limit ourselves to observations on one or two species only. This paper is devoted chiefly to a description of the observations on size and length-width ratio at the beginning of metamorphosis of larvae of the hard shell clam, *Venus* (*Mercenaria*) *mercenaria,* developing at different temperatures.

Certain aspects of the studies which provided data for this paper have already been described (Loosanoff, Miller and Smith, 1951). In brief, they consisted of growing larvae of *Venus* (*Mercenaria*) *mercenaria* at constant temperatures ranging from 15.0° to 33.0° C. at intervals of 3.0° C. Since fertilized eggs that were placed in water of 15.0° or 33.0° C. showed abnormal development and heavy mortality, few ever reaching veliger stage, growth of larvae at these temperatures will not be discussed here.

The work was done in winter, the time we find most convenient to control the water temperature (Loosanoff, 1949). Altogether, four experiments were conducted. However, in one experiment one of a pair of cultures grown at 24.0° C. was accidentally lost, while in the fourth experiment, which was conducted during a comparatively warm spell when low temperature was difficult to maintain, no cultures were carried at 18.° C. As is our practice, the water in the culture jars was changed every second day (Loosanoff and Davis, 1950). The larvae were fed a mixture of micro-organisms consisting principally of *Chlorella* sp.

Samples for larval measurements were taken 48 hours after fertilization and every second day thereafter, until metamorphosis. These samples consisted of 50 larvae measured at random from each culture vessel, *i.e.,* 100 larvae from each temperature group. The length represented the greatest distance between the anterior and

posterior shell margins, while the width was the distance measured from the tip of the umbo to the middle of the ventral shell margin.

Because the larvae could not be marked individually, their rate of growth and size at setting could not be recorded directly on this basis. For this reason we used two substitute criteria. One was the average length of the larvae on the day the setting was first observed in each culture, and the second, the maximum size of the larvae observed during the life of the culture.

The number of days required for setting to begin at the different temperatures in the four experiments is given in Figure 1. Clearly enough, there were differences between the cultures within the same temperature group and also between

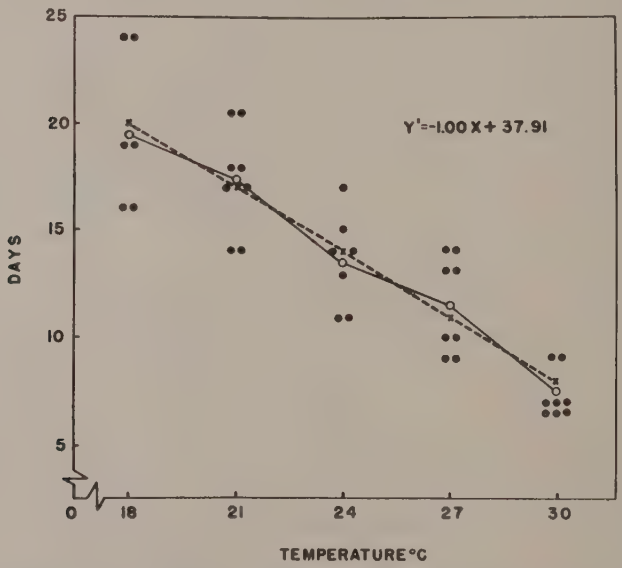

FIGURE 1. Number of days necessary for clam larvae to begin setting in cultures grown at different temperatures. ● = mean of individual culture; o = mean of all cultures grown at the same temperature; $\bar{x}$ = mean for given temperature predicted from regression line.

the groups carried at different temperatures. The most uniform results were obtained with the 30.0° C. group, where the beginning of setting in the different cultures varied between seven and nine days after fertilization, a difference of only two days. However, the difference between the shortest and longest periods needed for larvae to begin setting became greater in colder water. For example, in the 18.0° C. group the earliest beginning of setting was recorded 16 days after fertilization and the latest, after 24 days, a difference of eight days (Fig. 1).

An analysis of variance was carried out to test the significance of the differences among the different temperature groups on the number of days required for setting to begin. Since the result was highly significant (beyond the .001 level), separate

"t" tests were run for all possible pairs of temperature groups. All the "t" tests were highly significant (beyond the .01 level), with exception of the comparison between the 27.0° and 24.0° C. groups, and between the 21.0° and 18.0° C. groups. These results show, therefore, that a very strong relationship exists between temperature and date of setting, *i.e.*, larvae reared at high temperatures set significantly

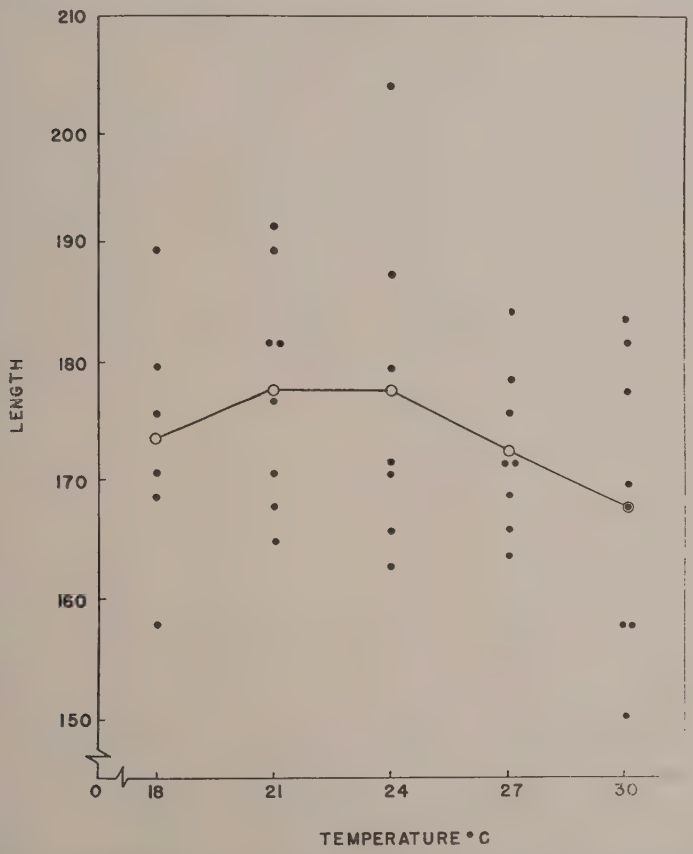

FIGURE 2. Mean length of clam larvae grown at different temperatures on day of beginning of setting. Measurements in microns. ● = mean of individual culture; o = mean of all cultures grown at the same temperature.

earlier than those raised at lower temperatures. This conclusion was expressed in the preliminary paper (Loosanoff, Miller and Smith, 1951).

Plotting of the dates of beginning of setting in the different cultures against the temperatures showed that the mean number of days for setting to begin for the various temperatures lies on an almost straight line (Fig. 1). Since the line con-

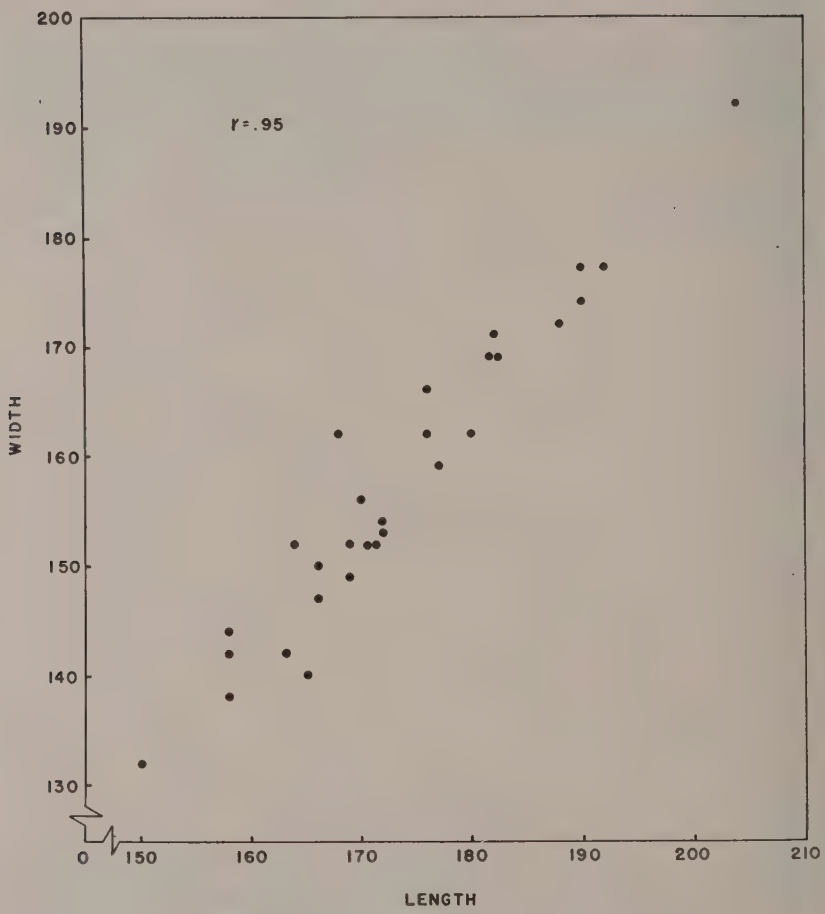

FIGURE 3. Mean length and width of clam larvae of individual cultures on day of beginning of setting. Measurements in microns.

necting the means of the different temperatures is obviously rectilinear, a regression equation was computed and found to be $Y' = -1.00\,X + 37.91$, where Y' is the predicted setting date and X is the temperature.

Because the regression line is an excellent fit to the experimental data, it is probable that interpolation within the 18.0° to 30.0° C. limits of the experiment can be made with a fair degree of confidence. However, extrapolation beyond these limits is not justifiable. This was shown by our other experiments, which demonstrated that clam eggs placed in water having a temperature of 15.0° or 33.0° C.

did not develop normally. Therefore, since the lineal regression does not hold even for a slightly higher or lower temperature, it cannot be expected to hold for lower or higher temperatures.

An analysis of variance test showed no significant differences among the five temperature groups, with respect to mean length of larvae at date of setting. Thus, although larvae grown at different temperatures required different periods to reach metamorphosis, in all cases they reach approximately the same mean length before setting. This observation indicates, therefore, that there was virtually no relationship between temperature and mean length at date of setting (Fig. 2). Nevertheless, the same figure shows that there was considerable variation in mean length at the beginning of setting among the various cultures within each temperature group.

In our studies we were also concerned with the shape, at metamorphosis, of larvae grown at different temperatures because, as has already been mentioned, the literature contains several remarks concerning variability of shape of larvae of the same species near setting time. Since the simplest method of describing the shape of a larva in mathematical terms for statistical analysis is to indicate its length-width ratio, measurements were made on larvae of all cultures, except those constituting the fourth experiment where no width measurements were taken, and the correlation between the mean length and the mean width of the larvae of each culture, on the day of the beginning of setting, was determined (Fig. 3). The

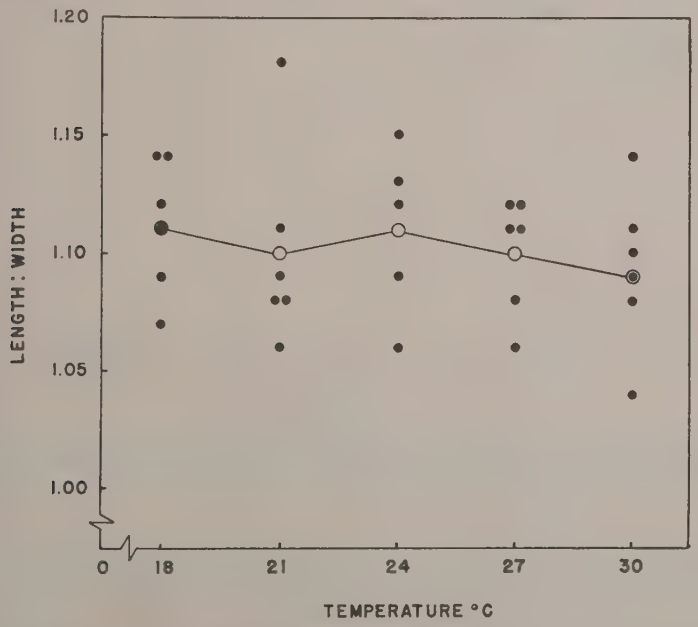

FIGURE 4. Ratio of mean length to mean width of clam larvae of different cultures on days of beginning of setting, in relation to temperature. ● = mean of individual culture; o = mean of all cultures grown at the same temperature.

results indicated this correlation to be so high ($r = .95$) that it seems unlikely that any analysis made using width as a variable would add anything new to that already made with length.

Continuing the analysis of data that might help in discovering the differences in shape of larvae grown at different temperatures, a study was made of the ratio of mean length to mean width at the date of setting. It failed to show the existence of any significant change in the ratio at different temperatures (Fig. 4). Thus, this matter has been satisfactorily solved to assure investigators working with lamelli-

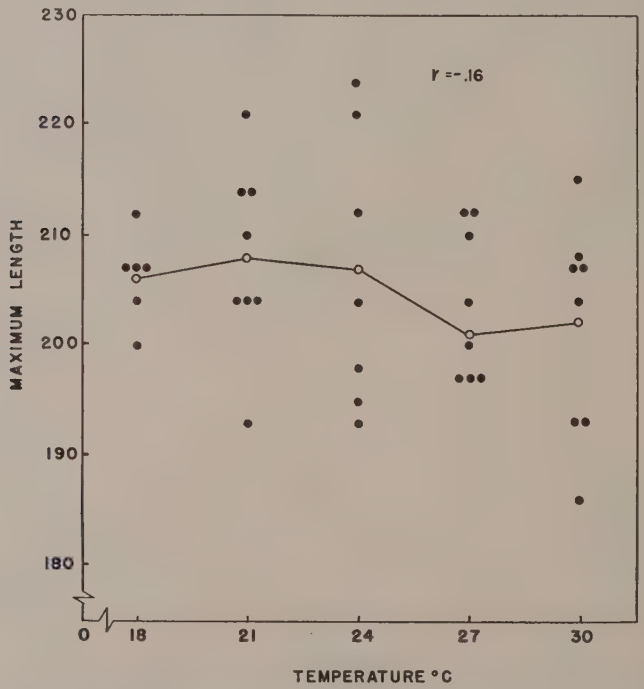

FIGURE 5. Maximum length of clam larvae of different cultures during the life of a culture, in relation to temperature. Measurements in microns. ● = mean of individual culture; o = mean for all cultures grown at the same temperature.

branch larvae that individuals of the same species display virtually the same shape at metamorphosis, even though they are grown at different temperatures.

Although our studies showed that even if larvae are grown at different temperatures, they, in all cases, reach approximately the same mean length before setting, the question still unanswered is whether there is an appreciable relationship between the *maximum* length of larvae on the date of setting and the temperature. A statistical analysis demonstrated the lack of an appreciable relationship

between these two variables, giving a correlation of − .16. The lack of relationship is clearly indicated in Figure 5, which shows that the means of the cultures grown at five different temperatures varied from 201 μ to 208 μ, a range of only seven microns. Nevertheless, we again noticed a considerable variability among the cultures within each temperature group, although it was much less pronounced within the 18.0° C. group than in certain others. However, again, no definite trend in this respect was observed because the variability of the maximum length of the

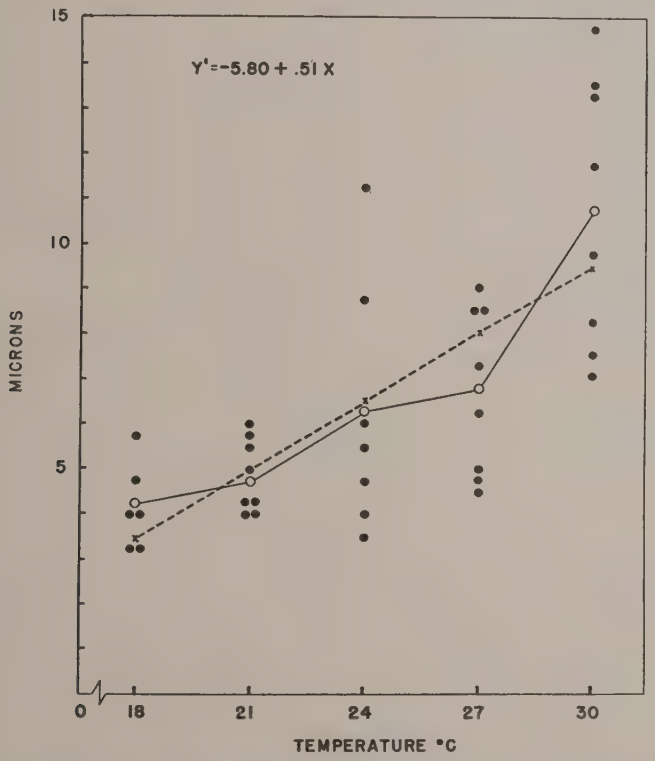

FIGURE 6. Average daily length increment of larvae grown at different temperatures. Measurements in microns. ● = mean of individual culture; o = mean of all cultures grown at the same temperature; x = mean for given temperature predicted from regression line.

larvae in the different cultures grown at 27.0° C., the second highest temperature group, did not differ greatly from that recorded for the lowest, *i.e.*, the 18.0° C. group.

Using the data collected during these studies, we can calculate the average daily growth increment for all cultures at given temperatures. By plotting the average daily growth increment for each temperature group against the corresponding

temperature, an approximately rectilinear relationship becomes evident (Fig. 6). The regression equation computed was found to be $Y' = -5.80 + .51\ X$, where Y' is the predicted average daily growth increment and X is the temperature. The relationship indicates, naturally, that faster growth occurred at higher temperatures and, theoretically, from the regression equation it can be assumed that if the temperature were reduced to about 11.3° C., growth would stop completely.

In discussing our results it must be remembered that they are representative only for this series of experiments and that there are many factors which can change the daily growth increment. One of these, capable of lowering or increasing the rate of growth of larvae, is the quality of the food. In our experiments the larvae were fed a mixture of phytoplankton, consisting largely of *Chlorella.* However, recent studies of Davis and Guillard (1958) clearly showed that the growth of clam larvae varied greatly depending upon the kind of food they were given. Davis found that the larvae grew best when fed a culture of mixed flagellates, including *Isochrysis, Monochrysis, Dunaliella,* and *Platymonas,* while the larvae given *Chlorella,* two species of which were tried, grew considerably slower. In the same series of experiments Davis was able to demonstrate that the rate of growth of larvae of the American oyster, *Crassostrea virginica,* also varied greatly according to the kind of food organisms available.

Quantity of food organisms is another factor to be considered. Our earlier work (Loosanoff and Engle, 1947; Loosanoff, Davis and Chanley, 1953a) showed that heavy concentrations of food cells, such as *Chlorella,* usually seriously interfered with the feeding of adult oysters and that they also either killed the clam larvae or retarded their growth. Furthermore, they indicated that the optimum concentration of food organisms depended upon the kind and size of their cells. Since, in our experiments described in this article, the number of cells was not accurately determined and the food did not consist of pure cultures but of a mixture of many organisms, we do not know whether the clam larvae were fed the optimum food concentrations. This circumstance, however, does not invalidate our comparisons because all cultures were given food of the same quality and in the same quantity.

Finally, the effect of the concentration of larvae in the experimental cultures should be considered. Our studies (Loosanoff, Davis and Chanley, 1953b; Loosanoff, 1954) have shown that larvae in crowded cultures grow somewhat slower. However, the difference in the rate of growth of larvae in lightly-populated and those in densely overcrowded cultures was not too great. For example, we determined, at the end of the tenth day, that the mean length of larvae in the cultures containing only six individuals per cubic centimeter of water was 162 μ, whereas the mean length in the overcrowded cultures containing 52 individuals per cubic centimeter was 144 μ, or only 18 μ less than that recorded for lightly-populated cultures. Since, in the experiments described here, we began with the same number of larvae in all containers and because during the experiments no excessive mortality was recorded in any of the cultures, our larval populations in all jars were not much different from each other and, therefore, could not seriously affect the uniformity of the experimental conditions.

In concluding this article a brief reference to one more aspect of the role of water temperature on growth of bivalve larvae may be appropriate. It has frequently been reported that species living in warmer water have just as long a pelagic life as their

northern relatives, and that, at a given temperature, the eggs of the southern species cleave and develop more slowly than those of the northern species of the same genus (Fox, 1936; Thorson, 1950). This suggests that even if the eggs and larvae were cultured under identical conditions, development of the eggs and larvae of the southern clam, *Venus* (*Mercenaria*) *campechiensis,* would require a longer period than is needed for eggs and larvae of the northern clam, *Venus* (*Mercenaria*) *mercenaria.* I had the opportunity to verify this contention by the studies conducted together with my associate, H. C. Davis. Adult *Venus* (*Mercenaria*) *campechiensis* were imported from the Apalachicola area of the Gulf of Mexico in November, 1953. Several weeks later these clams were conditioned for spawning. A group of large *Venus* (*Mercenaria*) *mercenaria,* natives of Long Island Sound, were ripened under identical conditions simultaneously with the southern species. When both groups were ripe, spawning was induced by our usual methods (Loosanoff and Davis, 1950). Fertilized eggs of each species and, later, larvae developing from these eggs were cultured under identical conditions, the temperature being approximately 21.0° C. Triplicate cultures of each species were grown, and random samples of 100 larvae from each culture were measured every second day. The curves constructed on the basis of this information showed that the rates of growth of the larvae of the two species were practically identical. Moreover, setting of larvae of both groups began at the same time. The results of this experiment contradict, therefore, the conclusion that when grown at the same temperature the eggs and larvae of the southern species develop more slowly than those of the northern species of the same genus.

I wish to express my thanks to Mrs. Barbara Myers for the statistical analysis of the data and to my associates, Miss Rita S. Riccio and Harry C. Davis, for their help in preparation of this article.

Summary

1. The mean setting dates for larvae of *Venus* (*Mercenaria*) *mercenaria* grown at constant temperatures of 30.0°, 27.0°, 24.0°, 21.0° and 18.0° C. were found to lie on an almost perfectly straight line according to equation $Y' = -1.00\,X + 37.91$, where Y' is the predicted setting date and X is the temperature.

2. There were no significant differences among the five temperature groups with respect to mean length of larvae at time of setting.

3. There was no apparent relationship between *maximum* length of larvae at time of setting and temperature.

4. The correlation between mean width and mean length of larvae at time of setting was very high ($r = .95$).

5. No apparent relationship was found between shape of larvae (*i.e.,* ratio of mean length to mean width) at time of setting and temperature.

6. The average daily growth increment for all cultures at given temperatures under the conditions prevailing during the experiments was determined.

7. The rate of growth of larvae of the southern clam, *Venus* (*Mercenaria*) *campechiensis,* was the same as that of the northern species, *Venus* (*Mercenaria*) *mercenaria,* when the temperature and other conditions were identical. Moreover, setting of larvae of both species began at the same time.

LITERATURE CITED

Brooks, J. L., 1946. Cyclomorphosis in Daphnia. I. An analysis of *D. retrocurva* and *D. galeata. Ecol. Monographs,* **16**: 409–447.

Coker, R. E., 1947. This Great and Wide Sea. The University of North Carolina Press, Chapel Hill, N. C., pp. 1–325.

Davis, H. C., and R. R. Guillard, 1958. Relative value of ten genera of micro-organisms as foods for oyster and clam larvae. *U. S. Dept. of the Interior, Fish and Wildlife Service, Fish. Bull. 136,* **58**: 293–304.

Erdmann, W., 1934. Untersuchungen über die Lebensgeschichte der Auster. No. 5 Über die Entwicklung und die Anatomie der "ansatzreifen" Larven von *Ostrea edulis* mit Bemerkungen über die Lebensgeschichte der Auster. *Wiss. Meeresunt. Abt. Helgoland.,* **19**: 340–341.

Fox, H. M., 1936. Rates of cleavage of sea urchin eggs in different latitudes. *Nature,* **178**: 389.

Hedgpeth, J. W., 1957. Treatise on marine ecology and paleoecology. Waverly Press, Baltimore, Md., **1**: 1–1296.

Jørgensen, C. B., 1946. Reproduction and larval development of Danish marine bottom invertebrates. 9. Lamellibranchia. *Medd. Komm. Danmarks Fisk. Havunders. Ser. Plankton,* **4**: 277–311.

Kofoid, C. A., 1930. Factors in the evolution of the pelagic Ciliata, the Tinntinnoinea. *Western Soc. Nat. Contr. Marine Biol., 1–39.*

Lebour, M. V., 1938. Notes on the breeding of some Lamellibranchs from Plymouth and their larvae. *J. Mar. Biol. Assoc.,* **23**: 119–145.

Loosanoff, V. L., 1949. Method for supplying a laboratory with warm sea water in winter. *Science,* **110**: 192–193.

Loosanoff, V. L., 1954. New advances in the study of bivalve larvae. *Amer. Scientist,* **42**: 607–624.

Loosanoff, V. L., and H. C. Davis, 1950. Conditioning *V. mercenaria* for spawning in winter and breeding its larvae in the laboratory. *Biol. Bull.,* **98**: 60–65.

Loosanoff, V. L., and J. B. Engle, 1947. Effect of different concentrations of micro-organisms on the feeding of oysters (*O. virginica*). *Fishery Bull. 42 of Fish and Wildlife Service,* **51**: 31–57.

Loosanoff, V. L., H. C. Davis and P. E. Chanley, 1953a. Behavior of clam larvae in different concentrations of food organisms. *Anat. Rec.,* **117**: 586–587.

Loosanoff, V. L., H. C. Davis and P. E. Chanley, 1953b. Effect of over-crowding on rate of growth of clam larvae. *Anat. Rec.,* **117**: 645–646.

Loosanoff, V. L., W. S. Miller and P. B. Smith, 1951. Growth and setting of larvae of *Venus mercenaria* in relation to temperature. *J. Mar. Research,* **10**: 59–81.

Murray, J., and J. Hjort, 1912. The Depths of the Ocean. London, Macmillan, pp. 1–821.

Stafford, Joseph, 1912. On the recognition of bivalve larvae in plankton collections. *Contr. Canad. Biol. Rep. XIV, 221–242.*

Sullivan, C. M., 1948. Bivalve larvae of Malpeque Bay, P. E. I. *Bull. Fish. Res. Bd. Canada,* **77**: 1–36.

Thorson, G., 1950. Reproductive and larval ecology of marine bottom invertebrates. *Biol. Rev.,* **25**: 1–45.

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Three Maine Cetacean Records

By Donald F. Mairs and Leslie W. Scattergood

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Bureau of Commercial Fisheries
Boothbay Harbor, Maine

Inasmuch as the distribution of smaller cetacea in our waters is but poorly known, we feel that pertinent observations on these mammals should always be entered into biological journals; even when "common" species are concerned, such records are essential to a better understanding of cetacean distribution in the North Atlantic.

A recent well-documented record of interest is that of a killer whale, *Grampus orca* (Linnaeus), which grounded at Tenant's Harbor, Maine on December 14, 1957. Mr. Hugo Lehtinen, a local fisherman, identified it and estimated that it was twenty feet long. Excellent photographs of the animal allowed us to confirm his identification. This whale's size indicates that it was probably an adult; the fact that it lacked the high dorsal fin and long flippers characteristic of males of this species can be interpreted to mean that the specimen was a female. Lehtinen hauled the whale off the beach on which it grounded on December 14, but it again stranded on December 15; it had disappeared by December 16.

Miller and Kellogg (1955, U. S. Nat. Mus. Bull. 205:661) and Hall and Kelson (1959, The Mammals of North America: 825) give the range of *G. orca* as Greenland south to New Jersey. There are, however, few documented records of killer whales along the Maine coast. Norton (1930, Proc. Port. Soc. Nat. Hist., 4(1):101) states that a killer whale stranded at Harpswell on November 14, 1904 and was later taken to Portland, exhibited, and mounted; in the same publication Norton also mentions several sight records by persons other than himself. Sergeant and Fisher (1957, Jour. Fish. Res. Bd. Can., 14(1): 97) list seventeen records of this species in eastern Canadian waters from 1947 to 1954, but only one of these was from Gulf of Maine waters.

During the first part of July 1958, a young harbor porpoise, *Phocoena phocoena* Linnaeus, was found floating dead near shore in Boothbay Harbor (Figure 1), Mr. Lou Garcelon, the finder, gave

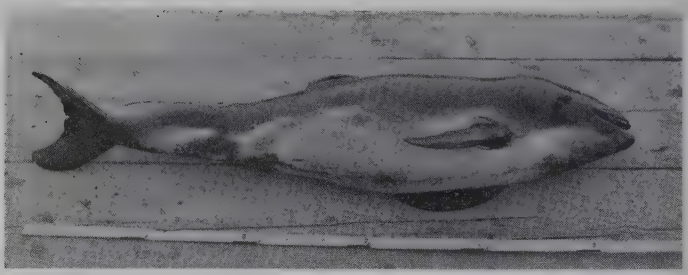

FIGURE 1. Harbor porpoise found dead in Boothbay Harbor.

us the mammal for study. It measured thirty-three inches in length and weighed fifteen pounds. This species is without doubt the most commonly observed cetacean along the Maine coast in summer. Hall and Kelson (*op. cit.*:831) have given its range as Davis Strait to the New Jersey-Delaware border.

On August 14, 1958, Mr. Garcelon, who operates the Boothbay Harbor sport-fishing cruiser *Lassie,* was tuna fishing ten miles south of the Damariscove Island whistling buoy when a large school of Atlantic blackfish or pilot whales, *Globicephala melaena* (Traill), appeared in the area. The animals were apparently chasing squid and were not at all wary of the boat, so an attempt was made to harpoon one. A medium-sized individual was selected and struck with the iron; it succumbed after about fifteen minutes of rushing about on the surface and was towed back to Boothbay Harbor. Captain Garcelon called the Bureau of Commercial Fisheries Biological Laboratory for a confirmation of his identification and offered the animal for study. Mairs examined and identified it as *Globicephala melaena;* this was later confirmed by Scattergood. On August 15, Mairs and several student assistants partially dissected the whale, which was a female measuring ten feet, eight inches. The iron had pierced the animal's left lung and continued into the pericardium. The heart was removed and preserved and, with the skull, was taken to the University of Maine. In the laboratory, a larval cestode was removed from a cyst on the posterior surface of the right kidney. In the stomach were twenty-five short-finned squid *Illex* (*Ommastrephes*) *illecebrosa* (Leseur); Captain Garcelon reported that the whale had another squid in its mouth when brought alongside. The short-finned squid is recorded by Sergeant and Fisher (*op. cit.*:101) as being the only food of black-fish which summer in the waters off

eastern Newfoundland; this is in interesting agreement with the food of the specimen reported upon in this paper. We found tenderloin steaks from the blackfish were rather oily and completely unique in flavor when broiled, but not unpalatable.

Atlantic blackfish are apparently not at all uncommon off the Maine coast in late summer, but there is a scarcity of records. Norton (*op. cit.*: 102) states that the species is of frequent occurrence in the Portland area and mentions records of several large schools in Casco Bay. Captain Garcelon said that there were about one hundred whales in the school from which he took the individual reported here. Many of these were cows with young calves; this was the largest herd he had ever seen locally. On August 16, 1958, Captain Garcelon saw a school of about fifty individuals five miles southeast of Pumpkin Rock off Boothbay Harbor. Hall and Kelson (*op. cit.*:828) give the range of the species as Greenland to Virginia.

An extensive fishery for the Atlantic blackfish exists in Newfoundland; the catch there varied from 3,100 to 6,412 for the years 1951-1955 according to figures given by Sergeant and Fisher (*op. cit.*: 101). In New England, stranded specimens in the Cape Cod area of Massachusetts are often butchered to remove the jaws and head "melon," both of which yield a fine grade of lubricating oil.

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A NEW METHOD OF HANDLING LONGLINE GEAR
A DESCRIPTION OF POFI "TUB" GEAR

by

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act

Modifications to Japanese-type longline gear, by the introduction of a large, rotating tub from which the line is handled, have ed in a considerable saving in manpower. Conventional gear can be operated in this manner with few changes. Instead of using dual baskets of line which must be separated and joined together for each day's fishing, a continuous mainline is set from, and hauled a wooden storage drum. This innovation is the product of continuing studies to increase the efficiency of longline gear.

Une nouvelle méthode de manipulation des palangres Description de la baille à lignes POFI

né

On a obtenu une importante économie de main-d'oeuvre grâce à des modifications apportées aux palangres japonaises par l'intron d'une grande baille tournante dans laquelle se trouvent les lignes. L'engin habituel peut être manoeuvré de cette façon avec peu de ements. Au lieu d'utiliser des paniers individuels de lignes qui doivent être désassemblées et réassemblées chaque jour pour la pêche, on l'eau et on récupère dans une baille de bois une ligne principale continue. Cette innovation est le résultat de recherches en cours pour enter le rendement des palangres.

Nuevo método para manipular palangres. Descripción del "tambor" POFI para enrrollar palangres

cto

Las modificaciones introducidas a los palagres de tipo japonés mediante el uso de un "tambor" rotatorio desde el cual se manipula arejo de pesca economiza bastante mano de obra; además permite usar unidades de tipo convencional con sólo pequeñas modificaciones. ar del empleo de varias cuerdas madres que es necesario unir y separar en cada salida, se procede a calar y a levantar una sola alma- en el "tambor" de madera. Esta innovación es el producto de continuos estudios para aumentar la eficacia de los palangres.

HE Pacific Oceanic Fishery Investigations (POFI) of the U.S. Fish and Wildlife Service has found longlining to be an effective means of catching in the relatively baitless waters of the central c. This report describes a new method of fishing ne gear recently developed at POFI following a stion by Mr. A. K. Akana Jr., POFI fleet supervisor. longline gear previously used by POFI was copied conventional Japanese designs and, although ate as a sampling tool for exploratory fishing, it ed too many men, by American standards, to be for commercial use. The so-called "tub" gear ped below is the most successful effort to date to ve the efficiency of gear in this respect, in that it s a material reduction in the manpower required rate longline gear.

essence of the tub method lies in a novel means ndling the mainline. Instead of the individual s of conventional gear, which must be separated ined together for each day's fishing, tub gear mainline of one continuous length which is shot nd hauled into, a large wooden storage drum or Branchlines and floatlines are removed from the mainline as they come aboard and are reattached during shooting operations.

The tub method requires only minor changes in the design of conventional longline gear. Standard POFI gear, or any longline with detachable branchlines and floatlines, may be used by adding "D" rings (described below) to the mainline.

DESCRIPTION OF THE GEAR

The gear is of a flexible design so that it can be altered readily to meet the changing requirements of an exploratory fishing programme. Components are detachable and can be assembled so as to fish varying numbers of hooks at different depths.

Shown in fig. 1 is a schematic representation of a single unit, or basket, of POFI gear of the latest type. Sixty to a hundred such baskets are joined together to make a fishing set.

Mainline

The mainline of each unit is made up of fourteen identical sections knotted together by double sheet bends. Each

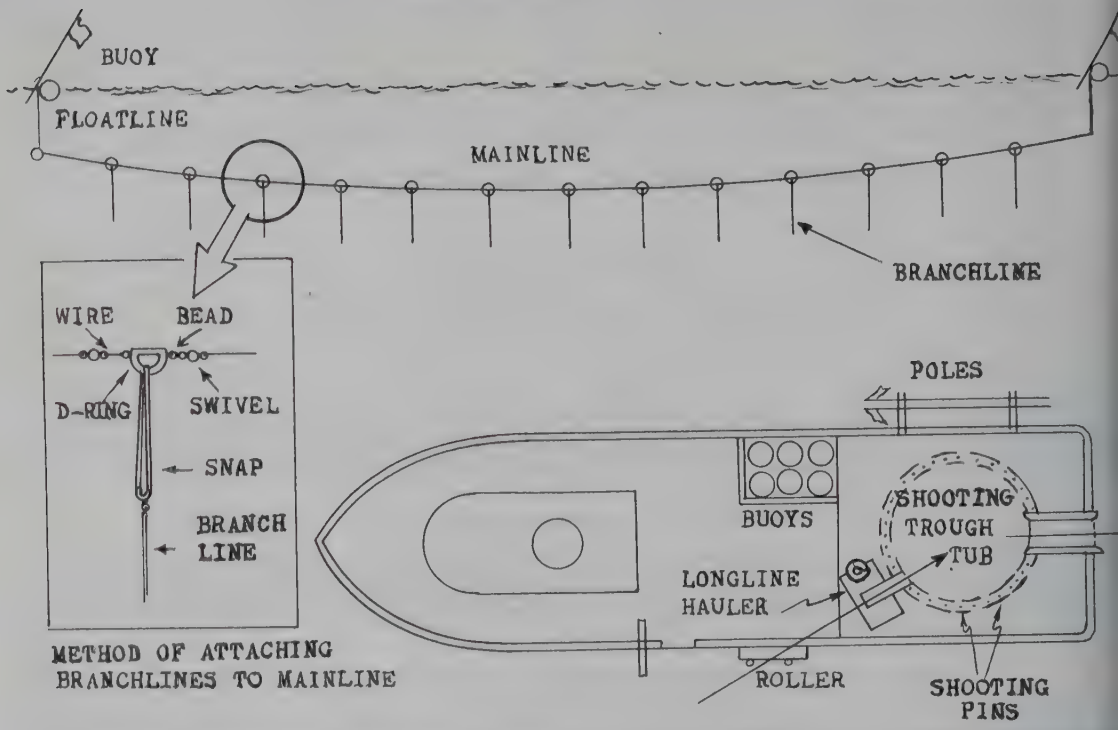

Fig. 1. Schematic drawing showing the arrangement of a single unit, or "basket", of POFI longline gear, and the location of the line storage tub on the stern of the vessel.

section consists of a 15 fm. length of preserved 261 thread hard-laid cotton twine with an eye splice in one end and a wire bridle with swivels, "D" ring, and pigtail at the other. Baskets are joined by a clover-leaf knot which is formed with an extra loop for attachment of the floatline.

Attachment of branchlines

The branchlines are attached to the mainline by the "AK" snap and "D" ring arrangement shown in fig.1. The "D" ring eliminates a troublesome defect of old gear. Formerly, "AK" snaps were clipped directly to a wire bridle. This type of attachment permitted the branchline to swivel around the mainline and prevented tangles when gear was being hauled aboard ship. But sometimes it failed to function properly when large fish pulled the branchline parallel to the mainline. At acute angles of pull, the snap ceased to have any swivelling action and sometimes was pulled out of shape or broken. The "D" ring maintains proper swivelling action. Rings are fabricated from stainless steel tubing with a lower section formed in a U shape and welded to the upper, straight tube section through which the bridle is rove. The wire bridles are made of a 6 in. length of 3/32 in. diameter 7×7 stainless steel wire rope with swivels connected to each end by means of Nicopress fittings. These fittings consist of malleable copper sleeves which are pressed on the wire by a ha tool. Brass beads threaded on the wire on both sic of the "D" ring act as miniature thrust bearings, a aid the swivelling action of the "D" ring. The br swivels relieve torque on the mainline which occ when the line is being brought in by the hauler.

Branchlines, snoods and hooks

The branchlines are made of 2 fm. lengths of 261 thre line. An "AK" snap is spliced into the upper e The lower end terminates in an eye splice for secur snood and hook. The snoods are fashioned of 6 lengths of ·066 in. diameter 7 strand galvanised wi The upper end of the snood is fitted with a section ⅜ in. rubber tubing which serves as chafing gear. T hooks, 8/0 or 9/0 tinned, are of a special shape w bent shank which allows them to hang in line w the snood.

Floatlines

Floatlines are made from 10 fm. lengths of 261 thr line. The lower end of each line has an "AK" snap attachment to the mainline. Snaps are clipped to lo in the line, rather than to "D" rings, since it has b found that "D" rings and wire bridles do not hold under the incessant jerking caused by the rise and of floats with sea and swell.

age tub

wn in fig. 1 is a schematic drawing of the wooden used for storage of the mainline. The experimental el used aboard the Fish and Wildlife vessel, "John Manning", is a double-walled plywood cylinder suring 12 ft. in diameter and 4 ft. in depth. The city is sufficient for the storage of 100 baskets of . For greater ease in shooting the tub is mounted the stern of the vessel, but adequate space between nd railing is left all around. The drum is supported ie centre by a heavy bearing bolted to the deck; outer edge runs on cast iron rollers of the type used upport the turntable of a purse seining vessel. forcing bands of 3 in. strap metal are welded around utside of the tub for extra support, and 33 stainless shooting pins are spaced at equal intervals inside the

e gear is hauled by means of a longline winch of entional Japanese design. Electrically powered by p. motor, the winch brings the line in at a maximum of about 1,000 ft./min. and coils it down automatic- vith only slight assistance from the winch operator. hauler is mounted so that the line is thrown just the edge of the tub.

e shooting trough, similar in design to that used Northwest Pacific halibut fishery, is a demountable metal form used to guide the outgoing mainline g shooting.

RATION OF THE GEAR

ıration

e sailing, baskets of mainline are joined together ed through the Japanese line hauler into the tub. ttempt is made to coil the line down uniformly egular piles, but it is deflected by hand so that it enly distributed in thickness over the bottom of ub. As the "D" rings pass through the hauler, are caught and threaded upon the shooting pin st the hauler. All fourteen rings of one basket laced on the same pin and the knot marking the f the basket is looped on top. The tub is then d by hand until the next shooting pin comes in vith the winch. To avoid piling up the line, the ts are spaced on every other pin; when the tub ompleted one revolution, a second and finally a layer of line is laid over the first so that 99 baskets eld on 33 shooting pins. The tub is covered with vas tarpaulin to prevent the line from being dis- in rough weather.

ng

shooting the tub is rotated by hand until the most basket comes under the shooting trough. essel is steered on a steady course at a speed of up nots. The buoy and floatline, marking the end of t, are attached to the mainline, which in turn is rough the trough, and the assembly is thrown ard. Thereafter the drag of the gear pulls the ne overboard as the vessel proceeds.

ks are baited with sardines, *Sardinops caerulea* (Girard), or herring *Clupea pallasii* (Valenciennes). Individual branchlines are attached to the mainline by clipping the "AK" snap at the upper end of the branchline to the uppermost "D" ring. They are then laid in the shooting trough one by one with the hook and bait dangling overboard. Floatlines are attached in the same manner. As the end of each basket leaves the shooting pin, the tub is turned to keep successive baskets in line with the shooting trough.

Hauling

The gear is hauled through side rollers on the starboard side of the vessel. The mainline is led through the hauler and coiled into the tub. As branchlines come aboard, the winch is stopped momentarily and the "AK" snaps are removed from the "D" rings. The branchlines are coiled in specially built plywood boxes and are stowed with hooks exposed on one side and with the "AK" snaps held by clips on the other. Fish are gaffed and brought aboard through an opening in the bulwark. The line is stowed in the tub as described before, with three baskets of "D" rings being placed upon each pin.

Broken or tangled portions of mainline are removed by unknotting the line section junctions, repaired, and joined to the end of the mainline when fishing finishes. Because the sections are identical they need not be restored to their original positions.

CONCLUSIONS

Tub longlining, in particular, seems applicable to small vessels carrying a limited number of men.

The saving in labour is considerable. Since a basket of POFI gear weighs about 40 lb. when wet and a day's set may consist of up to 100 baskets, about 4,000 lb. of wet line would have to be cleared out and restowed by hand for each day's fishing, when using conventional methods. The POFI tub method eliminates all manhandling by flaking the line directly into the tub.

Five men were found sufficient to operate the gear, as against a crew of 11 men required for conventional gear. Both methods require, for each basket of line, about 1½ min. for shooting and 3½ min. for hauling.

Some difficulties in operation have been experienced, the most troublesome being excessive wear and tear on the mainline, due to the "D" rings running at high speed through the overside rollers and longline hauler. At high hauling speeds, "D" rings strike the rollers or hauler with enough force to bend the rings or break wire bridles. Much needed is a method of joining branchlines to the mainline by a system which permits swivelling freely in any direction but which offers little resistance to passage through the line hauler.

One difficulty anticipated, which failed to materialize, was fouling of the mainline during shooting operations. Provided that the shooting trough is properly designed, the outgoing mainline runs smoothly in it and fouling is less than when shooting by conventional methods.

All POFI tubs are rotated manually. Mechanical rotation has not yet been installed but, if used commercially, powered tubs should increase efficiency.

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BY

WALTER M. MATSUMOTO
U. S. FISH AND WILDLIFE SERVICE

WITH 31 FIGURES IN THE TEXT

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BAUCHOT-BOUTIN, L.: Revision synoptique du genre Serrivomer (Anguilliformes). Bull. du Mus. 25. Paris 1953.

BERTELSEN, E.: Notes on the Deep-Sea Angler-Fish *Ceratias holbölli* Kr. based on specimens in the Zoological Museum of Copenhagen. Vidensk. Medd. fra Dansk naturh. Foren., Bd. 107, 22 pp. København 1943. P.D.O.C.*) No. 27.

— A New Type of Light Organ in the Deep-Sea Fish *Opisthoproctus*. Nature, Vol. 181, pp. 862—863, March 22. 1958. P.D.O.C.*) No. 33.

BERTIN, L.: Des analogies entre le squelette maxillaire des *Saccopharynx* et des *Eurypharynx*, Poissons Apodes, et celui des Reptiles Ophidiens. Bull. de la Soc. Zool. de France T. LVII. No. 2. 10 pp. Paris 1932.

— Bases anatomiques de la classification des Poissons Apodes appartenant au sous-ordre des Lyomères. Compt. rend. de l'Acad. d. Sci. 27. Dec. 1932. 3 pp. Paris.

— Mise au point de la systématique des Poissons abyssaux appartenant aux genres *Saccopharynx* et *Eurypharynx*. Bull. Mus. Nat. d'Hist. Nat. 2e S. T. VI. No. 1. 6 pp. 1934. P.D.O.C.*) No. 1.

— Une nouvelle espèce de poissons abyssaux: Saccopharynx Schmidti. C. R. séances l'Acad. Sc. t. 198. 2 pp. 1934. Paris. P.D.O.C.*) No. 3.

— *Oxystomus* de Rafinesque est une forme bien distincte. parmi les larves leptocéphaliennes. C.R. séances l'Acad. Sc. t. 200, 3 pp. 1935. Paris. P.D.O.C.*) No. 5.

— Un type primitif de nageoire caudale chez les poissons du genre *Cyema* Günther. Bull. Soc. Zool. France. Tome 61. 7 pp. Paris. 1936. P.D.O.C.*) No. 11.

— Un nouveau genre de poissons apodes caractérisé par l'absence de machoire supérieure. Bull. Soc. Zool. France. Tome 61. 8 pp. Paris. 1936. P.D.O.C.*) No. 12.

— Sur une série de Leptocéphales appartenant au genre *Saccopharynx* Mitchill. C. R. séances l'Acad. Sc. t. 203, 2 pp. Paris 1936. P.D.O.C.*) No. 13.

— Contribution a l'éthologie des Poissons abyssaux. Bull. Mus. Nat. d'Hist. Nat. 2e S. T. VIII. No. 6. 6 pp. Paris. 1936.

— Déscription anatomique du genre *Stemonidium*, type peu connu de Serrivoméridés. Bulletin du Muséum de Paris. Sér. 2, T. XIII. 8 pp. Paris 1942. P.D.O.C.*) No. 26.

— Ostéologi du genre *Avocettinops* (Apode abyssal) et révision du sous-ordre des Nemichthyiformes dont il fait partie. Bull. Soc. Zool. France. Tome 67. 11 pp. Paris 1942. P.D.O.C.*) No. 24.

BRUUN, A. FR.: On some new Fishes of the Family Gonostomatidae. Vidensk. Medd. fra Dansk naturh. Foren., Bd. 92, 7 pp. København 1931. P.D.O.C.*) No. 9.

— On the value of the number of vertebrae in the classification of the Exocoetidae. Vidensk. Medd. fra Dansk naturh. Foren., Bd. 94, 10 pp. København 1933.

— Notes on the Linnean Type-Specimens of Flying-Fishes (Exocoetidae). Linn. Soc. London Journ. (Zool.) Vol. 39. No. 263. 3 pp. 1934. P.D.O.C.*) No. 2.

— Sur la distribution de quelques Poissons océaniques d'après les Expéditions Danoises. Bull. l'Inst. Océanograph. Monaco No. 700. 16 pp. 1936.

— Nordatlantens *Synaphobranchus*-Arter, Biologi og Udbredelse sammenlignet med Aals og Havaals. Nordiska (19. skandinaviska) naturforskarmötet i Helsingfors 3 pp. 1936.

— *Monolene danæ*, a new Flatfish from Panama, caught bathypelagically. Ann. Magazine Nat. Hist., Ser. 10. Vol. 19.

BRUUN, A. FR.: *Chascanopsetta* in the Atlantic, a bathypel gic Occurrence of a Flat-fish, with Remarks on Distrib tion and Development of certain other Forms. Videns Medd. fra Dansk naturh. Foren., Bd. 101, 11 pp. Køb havn 1937. P.D.O.C.*) No. 16.

— Observations on North Atlantic Fishes. 1. *Acanthocott lilljeborgi*. 2. The *Ammodytes lancea* Group. Videns Medd. fra Dansk naturh. Foren. Bd. 104. 18 pp. Køb havn 1941. P.D.O.C.*) No. 20.

— En Dybhavsgåde mindre, Posthornblæksprutten (*Spiru spirula* L.). Dyr i Natur og Museum. Aarbog for Unive sitetets zoologiske Museum 1941. 10 pp. København 19

BUEN, F. DE: Estados larvarios y juveniles de la Sarda sar (Bloch). Inst. Español de Oceanografia, Trabajos Núm. 32 pp. Madrid 1930.

— Formas Ontogénicas de Peces (Nota primera). Inst. E pañol Oceanografía, Notas Resúm. Ser. II, Núm. 38 pp. Madrid 1932.

BURKENROAD, M. D.: Preliminary descriptions of twenty-o new species of pelagic Penæidea (Crustacea decapod from the Danish Oceanographical Expeditions. An Magazine. Nat. Hist., Ser. 11. Vol. 6. 20 pp. 1940. Londo P.D.O.C.*) No. 18.

CARLGREN, OSCAR: The Actiniaria and Zoantharia of Helena. Vidensk. Medd. Dansk Naturh. Foren., Bd. 1 20 pp. 1941.

COLOMBO, BERNARDO: Contributo statistico ad un tentati di discriminazione biometrica di popolazioni o ra geografiche di teleostei del genere »Bregmaceros«. Acc Naz. Dei Lincei. Serie VIII, vol. XIX, 1955. 9 pp. Ro P.D.O.C.*) No. 46.

EGE, V.: On some new Fishes of the Families Sudidæ a Stomiatidæ. Vidensk. Medd. fra Dansk naturh. Fore Bd. 94, 14 pp. København 1933.

EINARSSON, HERMANN: Notes on Euphausiacea I—III. On t systematic value of the spermatheca, on sexual dim phism in *Nematoscelis*, and on the male of *Bentheuphaus* Vidensk. Medd. fra Dansk naturh. Foren., Bd. 106, 24 1942. P.D.O.C.*) No. 25.

FAGE, L.: Sur la localisation dans les eaux moyennes Pacifique d'un Mysidacé peu connu, *Ceratolepis ham* G. O. SARS. Compt. rend. de l'Acad. d. Sci., t. 200. 3 1935. Paris. P.D.O.C.*) No. 6.

— Sur un Ellobiopsidé nouveau, *Amallocystis fasciatus* g et sp. nov. Parasite des Mysidacés bathypélagiques. Ar Zool. Expériment. Générale. 1936. Tome 78, Notes Revue, No. 3. 10 pp. Paris. P.D.O.C.*) No. 10.

— A propros d'un Mysidacé bathypélagique peu con *Chalaraspis alata* G. O. Sars (Willemoes-Suhm *in* Arch. Zool. Expériment. Générale. 1939. Tome 80, No et Revue, No. 2. 9 pp. Paris. P.D.O.C.*) No. 17.

— Sur le déterminisme des caractères sexuels secondai des Lophogastrides (Crustacés-Mysidacés). Compt. re de l'Acad. d. Sci., t. 211. 3 pp. 1940. Paris. P.D.O.C.*) No.

FAGE, L.: Diagnoses préliminaires de quelques espèces nou les du genre *Lophogaster (Crust. Mysidacés)*. Bull. Mus. N d'Hist. Nat. 2e s., t. XIII, no. 6. 6 pp. 1940. P.D.O.C.*) No.

GÜNTHER, K. & DECKERT, K.: Über die synkranialen Gef stämme des Tiefseefisches Malacosteus niger A (Isospondyli, Malacosteidae). Zool. Beiträge. N. F. 2 pp. 1956. Berlin. P.D.O.C.*) No. 49.

HAGEN, F. VON: Die wichtigsten Endokrinen des Flu Zool. Jahrb., Abt. Anatomie, Ontogenie, Bd. 61, 72 pp.

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INTRODUCTION

tunas are of special interest to marine ecologists and fishery biologists. They constitute a major element the fish fauna of tropical and subtropical seas the world over, and they are of major economic im- nce, contributing an important share of the world protein resources. Information on the distribution bundance of tuna larvae is essential to our knowledge of the life histories of the tunas. Variations in distribution may possibly serve as an index to the distribution of adults which is often difficult or ssible to assess by the usual sampling methods.

related problem involves the difficulty of locating spawning grounds through gonad examination, prin- y because ripe females are only seldom taken, even in areas where spawning is known to occur and commercial fisheries exist. The infrequent capture of ripe females may be due to very rapid devel- nt of the eggs within a brief time interval in the final stage of maturity, or perhaps because females ripe eggs may undergo changes in feeding habits during this period. The latter may be one reason for reponderance of males in the catches of various tunas (Murphy and Shomura, 1953a, 1953b, and 1955) nay also account for the rarity of capture of females with near, or running, ripe gonads in the Hawaiian ck fishery (Brock, 1954). These problems may be approached by examining the tuna eggs and larvae in plankton nets, provided the eggs and larvae can be identified readily and accurately. The eggs arvae are largely planktonic at this stage of development, and the planktonic catches are not dependent the feeding habits of the spawning females.

e problem of identifying tuna larvae is an unusually perplexing one. The difficulty lies primarily in ing the juveniles which are indispensable to bridge the gap between the postlarval and adult stages velopment. In a few areas, such as off the Pacific coast of Central America, the Gulf of Mexico and entral Pacific islands (Line and Phoenix Islands), juveniles of yellowfin (*Neothunnus macropterus*), ck (*Katsuwonus pelamis*), little tunny (*Euthynnus yaito*, *E. alletteratus*, and *E. lineatus*) and frigate erel (*Auxis thazard*) have been captured under night-lights, but the occurrence of juveniles in other is unknown. Practically nothing is known of the distribution of juveniles of species not mentioned . Consequently, although it is possible to catch sufficient numbers of tuna larvae in plankton nets, it remely difficult to identify the larvae at the species level because of the scarcity of juveniles in collections. ere would be less difficulty in identifying the young, if tuna eggs could be fertilized artificially and wth series of larvae obtained. Judging from the dearth of published reports in this field of investi- , and from our own lack of success in capturing ripe adults, we believe that the identification of tuna by this method is highly improbable. Perhaps the closest approach to this method is the work by (1932a, 1932b, and 1933), who hatched and reared tuna eggs taken in plankton nets. Inasmuch as gs were collected in areas in which several species of tuna spawn, the specific identity of these larvae uspect.

e purpose of this paper is to describe the larvae of two genera of tuna, *Euthynnus* and *Auxis*, the adults ich have only minor commercial importance at the present time. The bulk of the material used was hed by the Carlsberg Foundation, Copenhagen, Denmark, from collections made by the "Dana" and Danish vessels from 1911 to 1938. Other specimens were obtained from the California Department of and Game, the Inter-American Tropical Tuna Commission, and the Gulf Fisheries Exploration and

Gear Research and the Pacific Oceanic Fishery Investigations[1] (POFI) of the United States Fish and Wi life Service. The years in which collections were made, names of vessels, number of stations with tuna sp cimens, number of hauls with tuna specimens, and total number of tuna specimens captured are summariz in table 1.

Table 1. Specimens of *Euthynnus* and *Auxis* obtained from various sources.

Source of material				Locality of capture	Species	No. of specimens	Size range in millimeters
Carlsberg Foundation, Copenhagen, Denmark							
Year	Vessel	No. of stations with tuna specimens	No. of hauls with tuna specimens				
1912	"Florida"	1	1	Mid-Atlantic Ocean	*Auxis* II[1]	1	7.5
1920–22	"Dana"	29	62	Western and Mid-Atlantic, Gulf of Mexico, and Caribbean Sea	*Auxis* I[1]	521	3.7–60.0
					Auxis II[1]	84	3.5–8.0
					Euthynnus alletteratus	47	4.6–11.6
					Euthynnus lineatus	132	5.0–18.6
					Euthynnus (sp. unknown)	6	3.7–6.0
1928–30	"Dana"	46	133	Mediterranean Sea, Gulf of Mexico, East Indies, Atlantic, Pacific and Indian Oceans	*Auxis* I[1]	908	3.5–36.0
					Auxis II[1]	677	3.7–8.0
					Euthynnus alletteratus	2	5.0, 6.5
					Euthynnus lineatus	4	5.0–7.5
					Euthynnus yaito	238	3.5–12.5
					Euthynnus (sp. unknown)	34	3.7–10.7
1933	"Pacific"	1	1	South China Sea	*Auxis* II[1]	7	4.5–8.5
1937	"Pacific"	1	1	East Indies waters	*Auxis* II[1]	1	5.5
U. S. Fish & Wildlife Service, Gulf Fisheries Exploration, Pascagoula, Mississippi				Gulf of Mexico	*Auxis thazard* (?)	140	19.5–84.0
					Euthynnus alletteratus	118	11.5–94.3
U. S. Fish & Wildlife Service, Philippine Fishery Program				Philippine waters	*Euthynnus yaito*[2]	40	33.5–178.5
Inter-American Tropical Tuna Commission, La Jolla, California				Pacific Ocean off Central America	*Auxis thazard*	21	15.0–50.0
California Department of Fish & Game, San Francisco, California				Pacific Ocean off Central America	*Euthynnus lineatus*	2	21.0, 27.0
					Auxis thazard	16	11.0–28.0

[1] *Auxis* I and II are discussed on pages 21 to 25.
[2] Specimens previously examined by Wade (1949) and now deposited at POFI laboratory.

The research leading to this paper was performed as a regular part of the author's duties as Fish Research Biologist of the United States Fish and Wildlife Service, Pacific Oceanic Fishery Investigatio Honolulu, Hawaii.

METHODS

The method of study followed was the same as that used in a previous paper (Matsumoto, 1958 Because the smaller specimens were still in the initial stages of development and lacked many of the char ters by which the adults are identified, other characters had to be found. Pigmentation in certain parts the body appeared the most promising, therefore, this character was used as the basic criterion, supp mented by other character differences.

The larvae were first separated into various groups, each group with a distinctive pigment pattern. Fr each of these groups a size series of typical specimens was selected and, wherever possible, extended to clude juveniles which were old enough for positive species identification. Several specimens of various si from each of these series were stained with alizarin, according to the method given by Lipman (1935),

[1] Effective January 1959, the name of the Investigations was changed to Bureau of Commercial Fisheries, Biological Laborat Honolulu, Hawaii.

es on the formation of bones and spines. All the descriptions and counts presented here are based on vations on the left half of the body, unless otherwise specified.

ecause there may be disagreement with other authors on some of the terms used here, it would be well fine them. With tuna it is difficult to draw a line between the terms "larva" and "postlarva" because fish do not pass through any well marked metamorphosis and the various organs develop gradually, more rapidly than others. Therefore, for the sake of simplicity, all individuals with less than the full y counts, especially in the first dorsal fin, are considered larvae. This normally includes specimens m. or less in total length. Specimens between 12 mm. and approximately 18 mm. are considered post- e. In specimens within this size range the anal opening, which on smaller individuals is situated at less half the distance from the pelvic to the anal fin origins, is relocated near the origin of the anal fin. All young tuna larger than 18 mm. are classed as juveniles.

her terms which might be misinterpreted are defined as follows:

otal or fork length: the body length measured from the tip of the snout to the fork of the tail when e tail is forked, and to the tip of the longest ray when the tail is not forked.

audal peduncle: the posterior part of the body between the last finlet and the base of the caudal fin.

GENUS *EUTHYNNUS*

Notes on Adults and Juveniles.

he taxonomy of the fishes of this group is in need of clarification. Much of the disagreement that exists be traced to insufficient details in the original descriptions and to attempts by later workers to revise enus on the basis of such descriptions. Some of the difficulties are due also to the indiscriminate estab- ent of species or subspecies whenever a slight external body difference was noted or whenever speci- were taken from different geographical localities. Fraser-Brunner (1950) recently revised the Scom- e on a worldwide basis, but despite this work and a previous study by the same author (1949), there l some disagreement concerning the nomenclature of the several species of *Euthynnus*. Consequently, is at present no single classification which is wholly accepted by the majority of workers.

ecause the correct identity of the adults must be established before a larval or juvenile tuna can be ned to a species, it is imperative that we examine and clarify the taxonomic position of the adults. 1915 Kishinouye described a specimen of *Euthynnus yaito* which was taken from the waters off ern Japan, and which he believed to be identical with Cantor's (1850) *Thynnus affinis*. The holo- of *affinis* was from Penang, most likely from the Strait of Malacca, but since Cantor described only xternal appearance of the fish, it was impossible for Kishinouye to decide whether his specimen was ical with Cantor's. Fraser-Brunner (1949), however, noted that the type specimen from Penang had erine teeth which Cantor had failed to mention in his description. This character agrees with nouye's observation on *yaito*. Wade (1950) examined a number of juvenile *Euthynnus* (33.5 to 178 mm. ngth) taken from the waters around the Philippine Islands and the Celebes Sea in the East Indies, identified them as *yaito*, after Kishinouye (1915). He made no mention of the presence of other *ynnus*, notably *affinis*, even though the specimens were taken in the general area where Cantor obtained *s*.

he author believes that Kishinouye's suspicion concerning the similarity of *E. yaito* and *T. affinis* may orrect. If so, the specific name *affinis* would have priority over *yaito*. However, because the description *finis* is inadequate, and because neither the type specimen nor other adult specimens of this species available for examination, no definite statement concerning the nomenclature can be made. There- the Indo-Pacific species is designated as *yaito* in this paper.

shinouye (1920) described another species, *E. lineatus*, which was taken off Manzanillo, Mexico. ough the description of this species was based on a single specimen, subsequent authors, Schaefer

and Marr (1948) and Godsil (1954), found supporting evidence for its permanent establishment. The authors noted 37 vertebrae in *lineatus*, as compared with 39 in *yaito* and *alletteratus* (table 2). Other identifying characters include fewer fin rays in the second dorsal and anal fins. A survey of the literature reveals that *lineatus* usually has 11 rays in the second dorsal and 12 rays in the anal fins, whereas *yaito* and *alle*

Table 2. Summary of adult characters from literature[1] and from observations by the author.

Character	*E. lineatus*	*E. yaito*	*E. alletteratus*
Vomerine teeth	Present, but weak	Present	Absent, but bony ridge evident
Gill rakers:			
Upper limb	7–11	7– 9	10–11
Angle	1	1	1
Lower limb	23–29	22–24	25–29
Total	32–41	29–34	36–41
First dorsal fin rays	14–15	14–16	14–16
Second dorsal fin rays	11–12; mostly 11	12–14; mostly 13	12–14; mostly 13
Anal fin rays	11–13; mostly 12	13–14; mostly 14	13–14; mostly 14
Vertebrae	20 + 17 = 37	20 + 19 = 39	20 + 19 = 39

[1] Godsil, 1954; Rivas, 1951; and Wade, 1950.

teratus normally have 13 rays in the second dorsal and 14 rays in the anal fin. Thus, the species designation of *lineatus* will be retained in this paper.

The Atlantic form, *E. alletteratus* (Rafinesque), requires no comment, since it is widely accepted as valid. It differs from *yaito* in the absence of vomerine teeth, and in the greater number of gill rakers on the first gill arch, being similar to *lineatus* in this respect.

Specimens of *E. alletteratus* from the Gold Coast seem to be somewhat controversial. There is a difference of opinion regarding the external markings of this species; Irvine (1947) states that "there may be some obliquely placed wavy stripes on the sides above the lateral line"; whereas Fraser-Brunner (1949 and 1950) depicts the same specimens, which he designated as *E. alletteratus aurolitoralis*, with definite crescentic markings along the dorsal part of the body above the lateral line. Godsil (1954) found in *lineatus* a progressive and continuous variation in markings from the normal to a pattern that approached the crescentic. A similar condition may occur in *alletteratus;* hence the crescentic markings of *aurolitoralis* Fraser-Brunner could be an extreme variation of *alletteratus*. Until more conclusive evidence in support of *aurolitoralis* as a distinct species is obtained, these fish are designated as *E. alletteratus* (Rafinesque).

Thus, unlike Fraser-Brunner, who separated the genus into 2 main species, each with a number of subspecies, the author believes that *Euthynnus* is composed of 3 species: *alletteratus*, *yaito* and *lineatus*.

The juveniles of each of the three species were identified without too much difficulty, since most of the adult characters were sufficiently developed. Of the 161 specimens of juvenile *Euthynnus* examined, 1[illegible] were identified as *alletteratus*, 40 were identified as *yaito*, and 3 were identified as *lineatus*.

All specimens of *alletteratus* within the range 18.5 mm. to 94.3 mm., had either 16 spines and 13 rays or 15 spines and 14 rays in the dorsal fins, the first combination representing the usual count. The number of spines in the first dorsal agreed with the count on adult *alletteratus* given by Rivas (1951). The anal ray numbered 14 on all the specimens. All 5 specimens stained in alizarin had 20 + 19 = 39 vertebrae. Although identical fin ray and vertebral counts were found in *yaito*, *alletteratus* was easily separated from *yaito* by its higher gill raker count. *E. alletteratus* larger than 40 mm. possessed 24 to 28 rakers on the lower limb of the first gill arch. These counts were within the range of 25 to 29 rakers found in the adults (table 2). On the other hand, *yaito* above 50 mm. had 22 to 23 rakers on the lower limb, and thus comparable to the adult counts of 22 to 24. Specimens of both species below 50 mm. had fewer rakers than the adult of the respective species; but in all cases *alletteratus* had a much higher count than *yaito*. The smallest *yai*

uring 35 mm., had 4 + 1 + 20 = 25 rakers, whereas *alletteratus* of comparable size had 7 + 1 + 24 = 32
s. Even the smallest *alletteratus*, measuring 25.5 mm., had a higher raker count (5 + 1 + 21 = 27) than
5 mm. *yaito*.

is generally believed that the adult *alletteratus* has no vomerine teeth. Therefore, the presence of
rine teeth in many of the larger juveniles of this species was puzzling at first. Sixteen out of 39 speci-
between 34 mm. and 94.3 mm. had no vomerine teeth. Of the remaining 23 specimens, 18 had 1 weak
istinct vomerine tooth, 3 specimens had 2 to 3 weak teeth, and 2 specimens had 4 fairly strong ones.
resence of these teeth in juvenile *alletteratus* contradicts the adult descriptions, but their presence may
ly a temporary condition. It is conceivable that the teeth are eventually lost, resorbed, or become
own by osseous material and appear as the "bony ridge" noted by Godsil (1954).

r juveniles of *yaito*, observations were made on the specimens collected and reported by Wade (1949),
are presently deposited at the POFI laboratory. Our identification agreed substantially with Wade's.
n ray counts, as well as the vertebral counts, were identical with those of *alletteratus*, but the vomerine
were stronger and more numerous. The gill rakers, as mentioned earlier, were fewer than in *alletteratus*
neatus. We had no specimens below 30 mm., but this did not unduly affect our larval identification.
ly 3 juveniles of *lineatus*, all taken off the Pacific coast of Central America, were available for exam-
n. Two of these specimens were captured by the California Department of Fish and Game and one
e "Dana". The material previously collected in the same general area just mentioned and identified
eatus by Schaefer and Marr (1948) was also available for study. This material included specimens
g in lengths from 29 to 86 mm. Our 3 specimens of *lineatus* have 15 spines in the first dorsal fin and
s in the second dorsal. The two larger individuals have 12 anal fin rays, whereas the smallest one has
ne low ray counts in both the second dorsal and anal fins clearly identify them as *lineatus*. In addition
se characters, a 26 mm. specimen, which was stained, shows 20 + 17 = 37 vertebrae. The gill rakers
+ 19 = 24) evidently are not developed completely, and there is a single strong vomerine tooth in each
two larger specimens. Except for the gill rakers, these characters agree with the description of juve-
by Schaefer and Marr (1948) and with the description of adults by Godsil (1954).

us, the 3 species of *Euthynnus* are clearly distinguishable down through the juveniles, which can be
with the series of specimens taken in plankton nets.

Descriptions of Larvae and Postlarvae.

nus lineatus Kishinouye

e description of this species is based on 135 specimens of *E. lineatus*, taken in the waters off the Pacific
of Central America by the "Dana" in 1920—22 and 1928—30.

e smallest specimen identified as *lineatus* measures 5.0 mm. (fig. 1). The general shape of the body
les that of other tunas (Matsumoto, 1958a), and the head is relatively large (about 37 percent of
al body length). The mouth is large and contains about 8 teeth on each side of both jaws (an

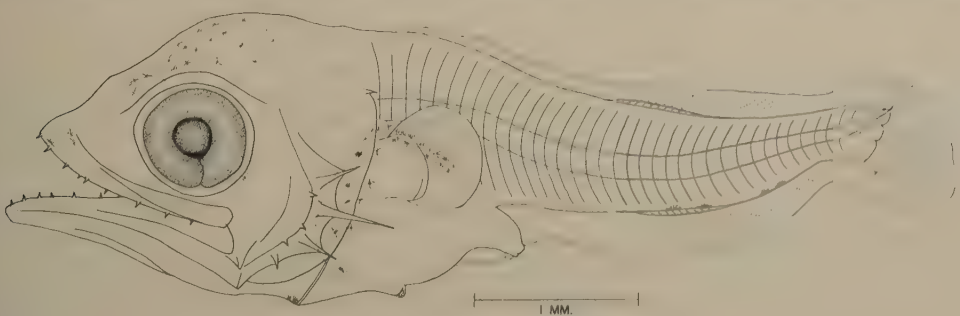

Figure 1. *Euthynnus* lineatus, 5.0 mm.

accurate count was not possible). The abdominal sac is short and triangular, and the anus is located ne the middle of the body. No indications of spine or ray development in the first dorsal and other fins a noticeable, and the pelvic fins are just emerging as small, fleshy buds. The body contains 38 or 39 myomer including the urostyle which is just beginning to turn dorsally.

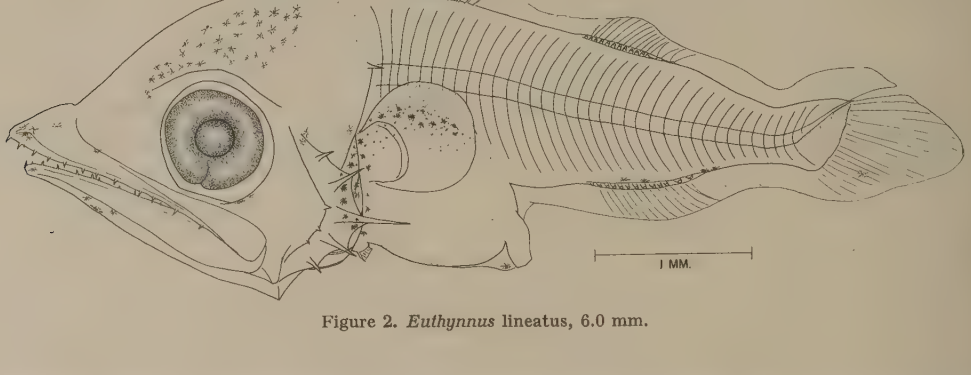

Figure 2. *Euthynnus* lineatus, 6.0 mm.

Pigmentation consists of chromatophores at the symphysis of the pectoral girdle and anterior to the an opening. Each side of the brain is well pigmented with 12 to 15 chromatophores over the midbrain and over the forebrain. Two chromatophores are present on the midventral line of the body along the base of t anal fin, and 2 more are seen faintly in the region of the middle anal "finlets". The lower jaw is unpigment at this stage of development.

The body parts undergo very rapid growth, which is already evident in a 6.0 mm. specimen (fig. 2 Five short spines are visible in the region of the first dorsal fin and posterior to these, 2 more are beginni to develop. The second dorsal and anal fin rays are poorly developed and are difficult to distinguish, b about 11 pterygiophores are observable. The caudal fin consists of 17 rays.

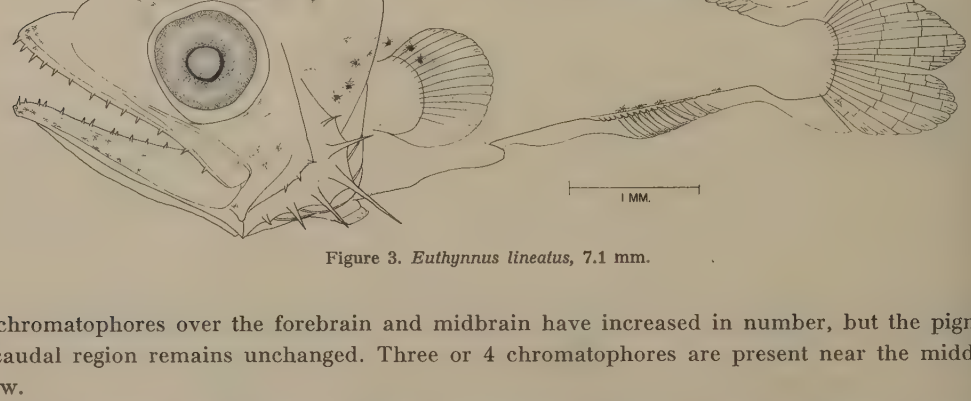

Figure 3. *Euthynnus lineatus*, 7.1 mm.

The chromatophores over the forebrain and midbrain have increased in number, but the pigmentati on the caudal region remains unchanged. Three or 4 chromatophores are present near the middle of t lower jaw.

A 7.1 mm. specimen (fig. 3) shows further developmental changes. The first dorsal fin consists of definite spines, the 6 anterior ones being the slightly greater in length. Three additional weak spines a beginning to develop. The fin rays are poorly formed, but 11 pterygiophores are developed in the seco dorsal fin and 12 in the anal fin. Similarly, about 5 indistinct basal elements of the dorsal finlets and basal elements of the anal finlets are beginning to develop. The caudal fin, which is beginning to fork, h

ell-developed rays, and the number of myomeres (38—39) is identical with that of the previous speci-

me striking changes are seen in the pigmentation. The first dorsal fin now has 6 large chromatophores en the second and sixth spines, and the first interspinal membrane is lightly tinged. In addition to the natophores at the tips of the upper and lower jaws, there are 7 more along the anterior two-thirds of wer jaw. Pigmentation over the forebrain and midbrain is more extensive, and several small chroma- res are present on the opercle posterior to the angle of the jaw. Although the figure does not show them, all chromatophores are present at the symphysis of the pectoral girdle.

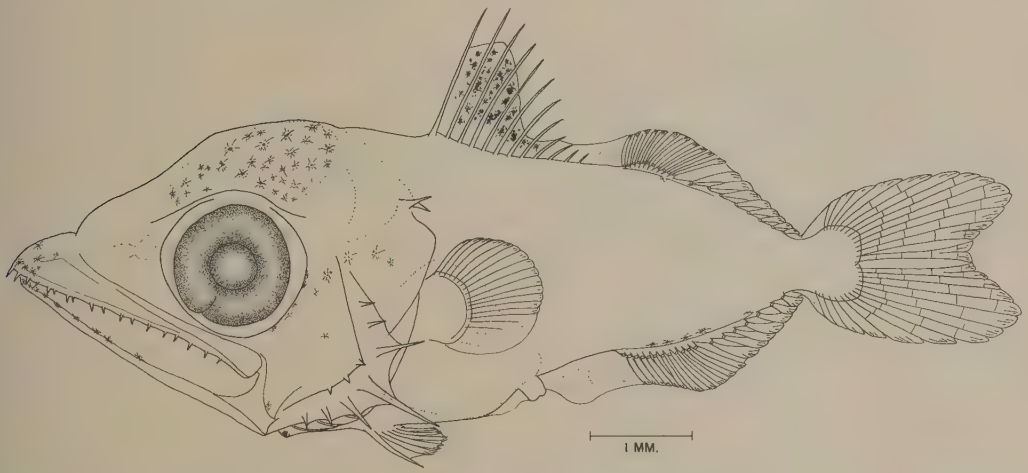

Figure 4. *Euthynnus lineatus*, 9.3 mm.

ne most noticeable difference between the previous specimen and the 9.3-mm. specimen (fig. 4) is the opment of the fins. The first dorsal fin consists of 12 well-developed spines; the longest one being about rcent of the body depth at the origin of the second dorsal fin. Elongate dorsal spines at this stage of opment are not limited to this species alone. Specimens of *alletteratus* and *yaito* also show similar opment, and it may be assumed that the spines grow at a relatively faster rate than the total body length the individual is between 9 mm. and 12 mm. in length. The second dorsal fin consists of 11 rays and finlets following it are not fully developed; each finlet being attached to its neighbor by persistent ele- of the median fin membrane. The first finlet is also attached to the last ray of the second dorsal fin. nal fin, with 12 rays, and the 7 finlets following it are also connected in a similar way. The enlarged fins are almost completely developed, and the pectorals now have about 14 distinct rays.

gmentation on the first dorsal fin extends over the first 8 interspinal membranes and is generally con- ted on the outer two-thirds of the fin. A single small chromatophore is present near the base of the ay of the second dorsal fin, and pigmentation on other parts of the body remain relatively unchanged. nyomere count is 38 or 39.

e body of the 10.6-mm. specimen (fig. 5) is beginning to resemble that of the juvenile. The abdominal as elongated, and the anal opening is only slightly anterior to the anal fin origin. The unpaired fins are t fully developed and consist of 15 spines, 12 rays, and 8 finlets in the dorsal, and 11 rays and 7 fin- the anal. The caudal fin contains the same number of rays, whereas the pectoral fin now consists well-developed rays.

gmentation over the forebrain and midbrain is more intense, but remains generally unchanged on parts of the head, on the first dorsal fin, and at the bases of the second dorsal and anal fins. The only pigmentation is along the base of the first dorsal fin, where a row of small, close-set chromatophores is evident.

A 12.0-mm. specimen (not figured) has characters similar to the 10.6-mm. specimen just described. T only differences are the presence of 3 chromatophores along the base of the second dorsal fin and 1 at the ba of the second dorsal finlet. In addition to these pigmented areas, a slightly larger specimen of 13.4 mm. (n figured) has 3 small chromatophores along the margin of the anterior half of the upper jaw. Staining bo

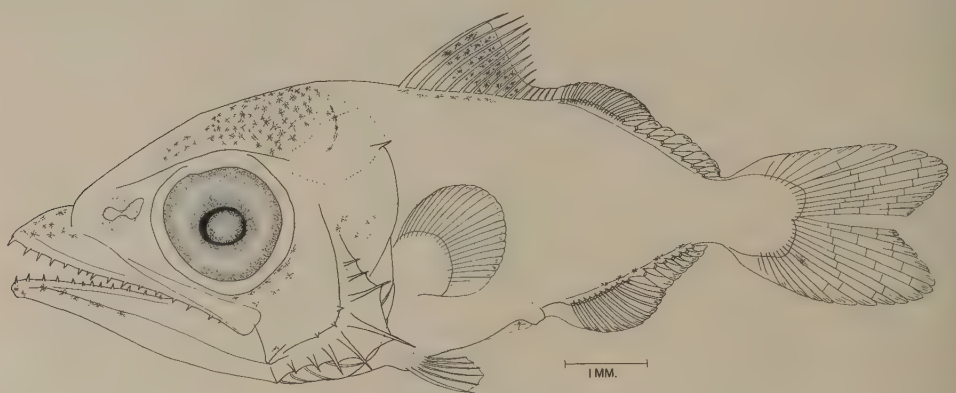

Figure 5. *Euthynnus lineatus*, 10.6 mm.

specimens with alizarin disclosed 20 + 17 = 37 vertebrae, and fin ray counts of 15 spines, 11 rays, and finlets in the dorsal and 11 rays and 8 finlets in the anal. The general body shape of these larvae resembl that of the 18.6-mm. specimen shown in figure 6.

In addition to these changes, there is yet another which, while it has no significance in specific identi cation, may be of general biological interest. The naris, which on smaller specimens is represented by single, ovate, indented nasal spot, gradually becomes more elongate with growth of the larva, and at som

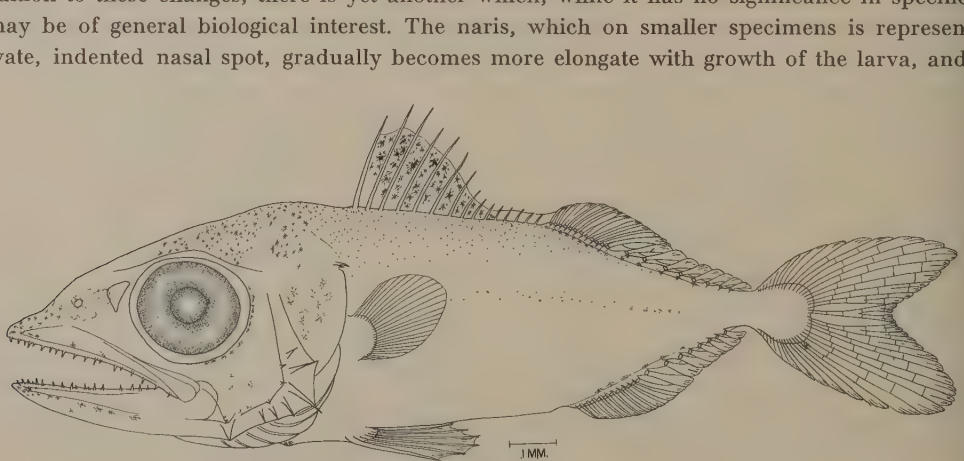

Figure 6. *Euthynnus lineatus*, 18.6 mm.

point between the 10.6-mm. and 12.0-mm. specimens it divides into two separate nares, a small, circula anterior naris and a larger, somewhat elliptical, posterior one.

The specimen depicted in figure 6 is quite similar to the larger juveniles in body form. This is due most to a gradual reduction in the head depth relative to the body length and to the elongation of the abdomin sac, so that the anal opening is closer to the anal fin origin. Other changes, though not quite as prominen can be seen in the more forward termination of the posterior margin of the upper jaw. In smaller specimen the end of the maxillary extends beyond a vertical through the posterior margin of the pupil. On the 18.6-mm specimen, however, the end of the maxillary does not quite reach the vertical through the posterior margi of the pupil.

h the 18.6-mm. specimen the fins and finlets are more clearly defined. The dorsal fins consist of the dult complement of 15 spines and 12 rays, followed by 8 finlets, whose tips are freee from each other. ases of the finlets, however, are still connected by a membrane. The anal fin, consisting of 12 rays, lowed by 7 finlets which are developed similarly to their dorsal counterparts. The caudal fin is well oped and more deeply forked, and the pelvic fins are longer. The pectorals, with 24 completely formed are comparable to the fully developed fins (24 to 26 rays) of the adults.

rther additions in pigmentation are noted on this specimen. The dorsal part of the body has a wide of chromatophores which tapers posteriorly to the base of the fifth dorsal finlet. A row of small chro-

Figure 7. *Euthynnus lineatus*, 21.0 mm.

phores is also present along the midlateral line of the body. These chromatophores extend from the tip e pectoral fin to a vertical through the base of the fourth dorsal finlet. The series of chromatophores the bases of the anal fin and finlets and also along the lower jaw remains relatively unchanged. Two y separated chromatophores are seen near the middle of the upper jaw, and the snout, forebrain, mid- and the surface of the opercle posterior to the eye show increased pigmentation. All the pigmented , except along the lower jaw, have extended rather rapidly, as can be seen on the 21.0-mm. specimen).

27.0-mm. specimen stained in alizarin has vertebral and fin ray counts identical with the 18.6-mm. nen, and the external appearance of this specimen is an exact duplicate of the 21.0-mm. specimen lbed above.

nnus alletteratus (Rafinesque)

ır description of this species is based on 68 specimens, ranging in sizes from 4.6 mm. to 18.0 mm. in ength, taken mainly by Danish vessels from the Atlantic Ocean and the Gulf of Mexico. Included in the figure are 19 specimens obtained by the United States Fish and Wildlife Service vessel *Oregon* in the of Mexico. Although specimens smaller than 4.6 mm. are present in the catches, they are not included e figure because species identification was not positive.

he general body shape of the 4.6-mm. specimen resembles that of the 5.5-mm. specimen shown in 8. In the former, there is no visible indication of spine or ray development in the unpaired fins. In- the fins are represented by a continuous membrane which starts in the region of the nape and extends d the caudal end of the body to the anal opening. The body contains 40 myomeres including the uro- the urostyle itself is undeveloped and extends posteriorly in line with the longitudinal axis of the body. romatophores are present at the symphysis of the pectoral girdle and along the midventral line im- ately anterior to the anal opening. The head is fairly well pigmented, with about 3 chromatophores over rebrain and about 12 over the midbrain. A row of 3 or 4 well-spaced chromatophores is already evident

over the middle two-thirds of the length of the lower jaw. About 11 are more or less evenly spaced along t midventral line in the posterior half of the body.

The 5.5-mm. specimen (fig. 8) shows some changes, the most distinctive being the development of 4 ve short spines in the first dorsal fin. The second dorsal, anal, and caudal fins are beginning to develop, a

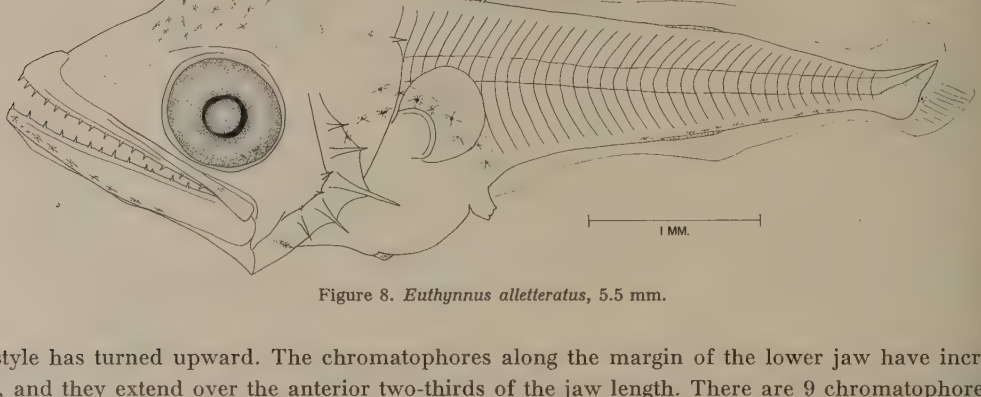

Figure 8. *Euthynnus alletteratus*, 5.5 mm.

the urostyle has turned upward. The chromatophores along the margin of the lower jaw have increased i number, and they extend over the anterior two-thirds of the jaw length. There are 9 chromatophores on t midventral line from the anal fin origin to the caudal peduncle. Each ramus of the upper and lower jaw bears about 14 teeth.

Evidently the species undergoes very rapid changes at this stage of development, for a 7.5-mm. specime (fig. 9) has 9 very long spines in the first dorsal fin, compared with only 6 spines on a 6.5-mm. specime Other fins are also well developed, with 12 or 13 rays in the second dorsal, 14 rays in the anal, and abo

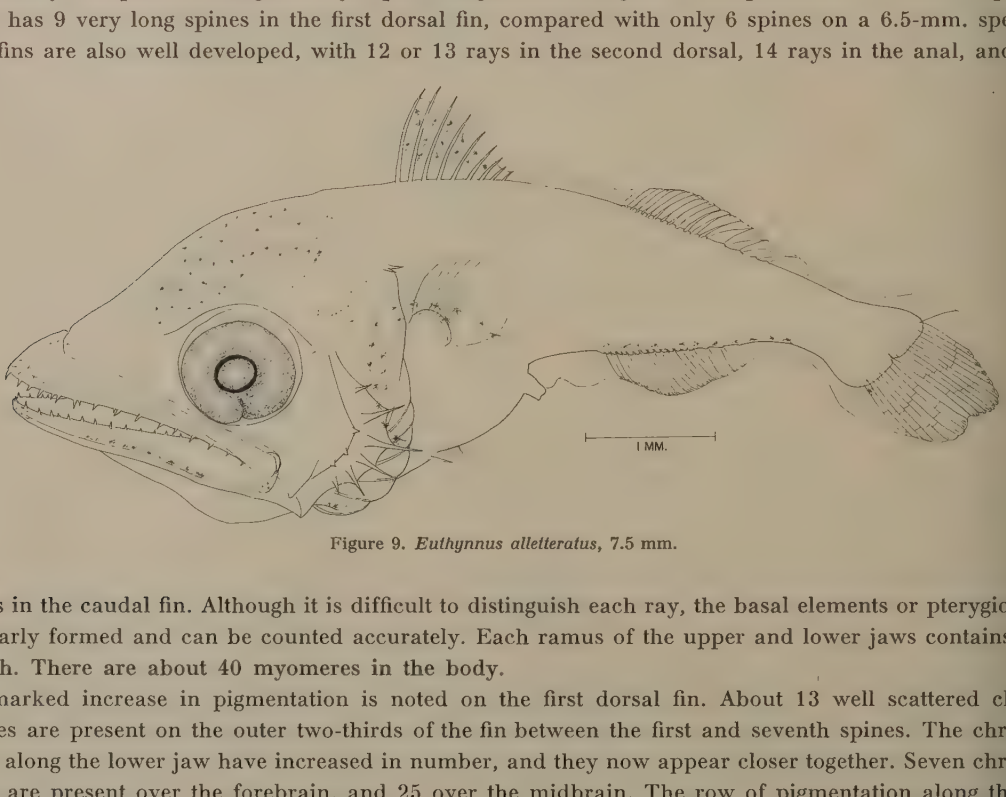

Figure 9. *Euthynnus alletteratus*, 7.5 mm.

17 rays in the caudal fin. Although it is difficult to distinguish each ray, the basal elements or pterygiophor are clearly formed and can be counted accurately. Each ramus of the upper and lower jaws contains abo 16 teeth. There are about 40 myomeres in the body.

A marked increase in pigmentation is noted on the first dorsal fin. About 13 well scattered chrom tophores are present on the outer two-thirds of the fin between the first and seventh spines. The chromat phores along the lower jaw have increased in number, and they now appear closer together. Seven chromat phores are present over the forebrain, and 25 over the midbrain. The row of pigmentation along the mi ventral edge of the body consists of about 11 regularly spaced chromatophores. On some specimens the

; many as 15 chromatophores. In addition to these, several small chromatophores are present at the f the snout and lower jaw.

rhaps the greatest development on the 9.3-mm. specimen (fig. 10) is the extremely long spines in the orsal fin. As in *lineatus* of comparable size, the length of the longest spine almost equals the body depth ured at the origin of the second dorsal fin. Both the second dorsal and anal fins have 13 rays, the giophores of which are clearly visible. Similarly, the pterygiophores of the dorsal and anal finlets are y noticeable. The caudal fin rays are well developed, and the posterior edge of the fin now shows of becoming forked. The pectoral fins consist of about 9 completely formed rays, and the ventral fins,

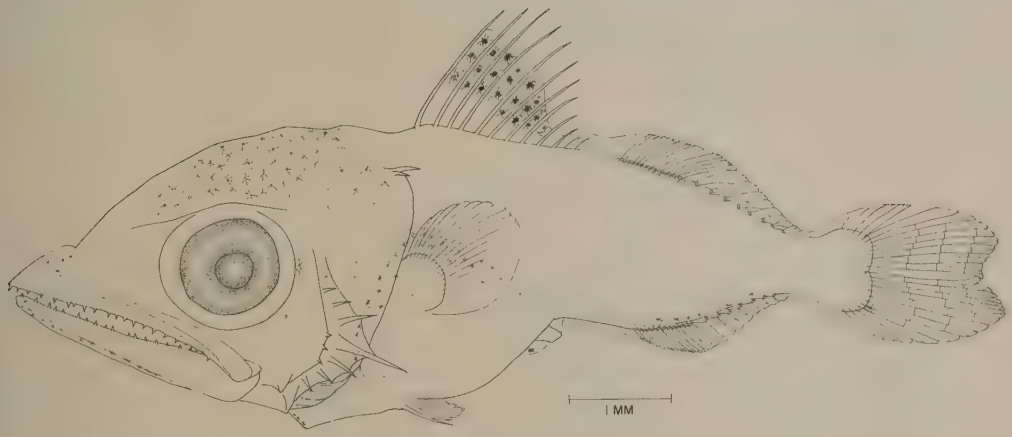

Figure 10. *Euthynnus alletteratus*, 9.3 mm.

were present on the 5.5-mm. specimen as small fleshy buds, are beginning to enlarge with the opment of a definite outer spine.

gmentation on the first dorsal fin is restricted to the outer half of the fin membrane, but the number romatophores has increased to 22 and they extend over 8 interspinous membranes. An increase in ntation over the midbrain is also noted, and 4 light, well-spaced chromatophores are evident on the f the head posterior to the eye. The rest of the head pigmentation appears unchanged from the pre- specimen. The series of chromatophores along the midventral line shows some variation, and on this nen only 6 chromatophores are present; 4 located along the posterior part of the anal fin base and 2 y spaced chromatophores located at the bases of the fourth and sixth anal finlets. Each ramus of the jaw now bears 20 teeth, and that of the lower jaw has 18; the number of myomeres is identical with f the previous specimens.

any changes are noted on the 10.6-mm. and 11.5-mm. specimens (not figured). Both of these have com- y developed dorsal and anal fins, consisting of 16 spines and 13 rays in the dorsal followed by 8 finlets, 4 rays in the anal followed by 7 finlets. The caudal fin is more clearly forked, and the pelvic fins increased in length. The myomere count on the unstained 10.6-mm. specimen remains the same as on reviously described specimens, and the 11.5-mm. stained specimen has 20 + 19 vertebrae. The stained nen also has 21 or 22 teeth and 23 or 24 teeth on each ramus of the upper and lower jaw, respectively. ne increase in pigmentation is evident in several places. The margin of the lower jaw bears two rows romatophores and the upper jaw has a single row of chromatophores along two-thirds of its length. arger of the 2 specimens has a third row of chromatophores along the anterior half of the lower jaw. t 4 or 5 closely grouped chromatophores are seen at the angle of the jaws, and about 8 large chromato- s are present on the surface of the opercle posterior to the eye. A band of pigment, about 4 chromato- s wide, is seen along the dorsal edge of the body. This band tapers to a single row of chromatophores out the twelfth dorsal spine and continues to the origin of the second dorsal finlet. The first sign of pig- ation, 1 or 2 chromatophores along the midlateral line of the body, is seen between verticals through the

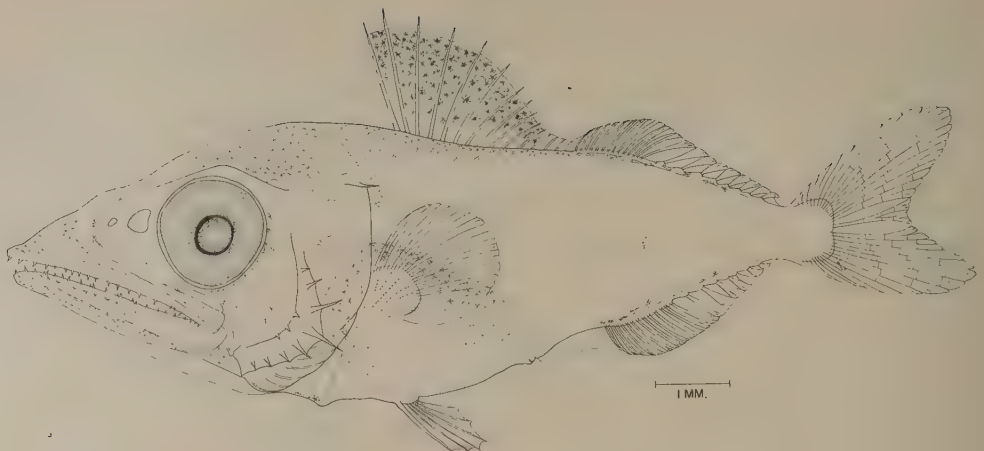

Figure 11. *Euthynnus alletteratus*, 12.0 mm.

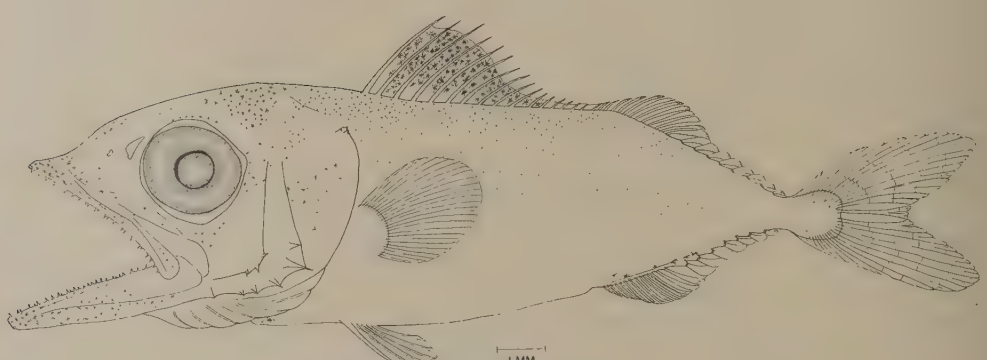

Figure 12. *Euthynnus alletteratus*, 18.5 mm.

Figure 13. *Euthynnus alletteratus*, 26.0 mm.

anterior and posterior end of the second dorsal fin. About 10 chromatophores are present along the ba of the anal fin and the first 4 anal finlets.

The characteristics noted above can be seen in the 12.0-mm. specimen shown in figure 11. Between t example and the 18.5-mm. specimen (fig. 12), the changes are quite distinctive. The shape of the body more like that of the larger juveniles due to the elongation of the abdominal sac and the more poster placement of the anus. The head parts, especially the mouth, appear smaller with respect to the total len of the body, and the fins and finlets are more clearly defined.

There is an increase in pigmentation over the head and dorsal half of the body, and the band of chromatophores along the midlateral line of the body is especially obvious.

Except for the first dorsal fin, the outline of which resembles that of the adult fin, and the narrower body relative to total length, there is very little difference between the 18.5-mm. specimen and the 26.0-mm. specimen of figure 13. The only perceptible change on specimens greater than 26.0 mm. is in the increase of pigmentation on the body. However, the change is so gradual that it is not evident until about 40 mm., when 1 to 3 very faint spots or vertical bars are seen along the dorsal third of the body. These bars increase in number to about 10 on a 58.0-mm. specimen (fig. 14), and to 13 on a 94.3-mm. specimen; the largest one examined in our collection. Superficially, at least, these larger specimens resemble the juveniles of *yaito* of WADE (1950). However, the 58.0-mm. specimen and others ranging in sizes from 40 to 94.3 mm. have total gill raker counts of 33 or more, with 25 to 28 on the lower limb of the arch. The *yaito* examined by WADE, on the other hand, had total gill raker counts of 30 to 32, with 22 to 23 on the lower limb, even though these were much larger specimens (127—175 mm.).

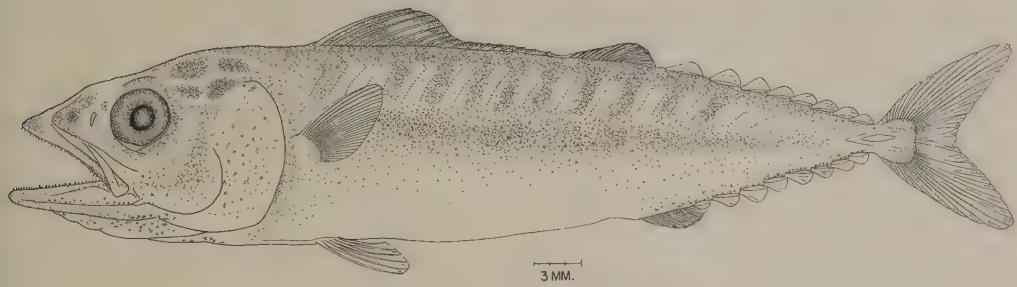

Figure 14. *Euthynnus alletteratus*, 58.0 mm.

All seven juveniles (25 mm., 30 mm., 30 mm., 40 mm., 45 mm., 63 mm., and 63 mm.) which were stained in alizarin have 20 precaudal and 19 caudal vertebrae, including the urostyle.

Euthynnus yaito KISHINOUYE

The study of this species is based on examination of 238 larvae and postlarvae taken mainly from the East Indies waters. A detailed description of this species, based on about 100 of the specimens mentioned above, is given in a previous publication (MATSUMOTO, 1958a). Although the species was only tentatively set as *yaito* in that paper, examination of additional material, including those of other species described in the previous sections, shows that the earlier identification is largely correct. In order to avoid needless repetition of the previous publication, only 4 characters, those most useful in separating *yaito* from other species, are discussed, and several of the previously used illustrations of *yaito* are reproduced here.

The first character we should like to review is the pigmentation of the lower jaw. Generally, a single chromatophore is present at the middle of the lower jaw in the smaller specimens. This is seen clearly in the 4.6-mm. specimen (fig. 15). The number of chromatophores increases to about 3 on a 7.6-mm. specimen (fig. 16), and to 4 or 5 on a 9.6-mm. specimen (fig. 17). These chromatophores are well separated from each other and are generally located in the anterior one-half to two-thirds of the lower jaw. Evidently this pigmentation increases slowly, for a 12.2-mm. specimen (not figured) has only 8 chromatophores over the entire length of the lower jaw.

The second character is the pigmentation along the ventral edge of the body near the caudal region. Five chromatophores are seen on the 4.6-mm. and 7.6-mm. specimens, whereas only 3 chromatophores appear on the 5.5-mm. specimen (not figured) and on the 9.6-mm. specimen. A 12.2-mm. specimen shows 4 chromatophores. Thus, although there is some variation in the number of chromatophores along the ventral edge of the body, it does not seem to be related to the size of the specimen. On the 12.2-mm. specimen,

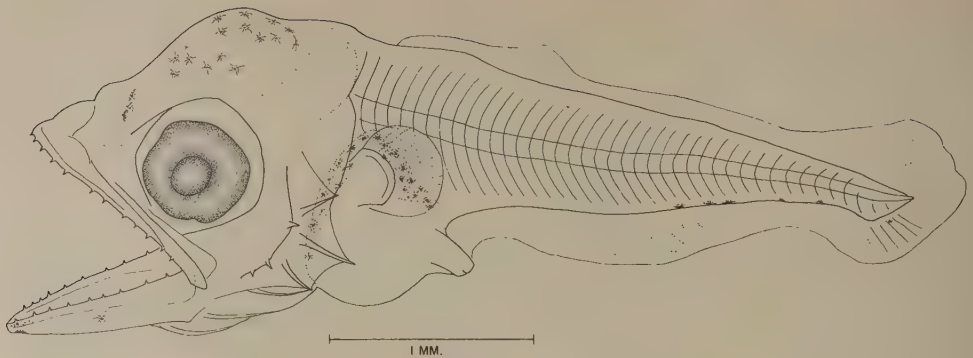

Figure 15. *Euthynnus yaito*, 4.6 mm.

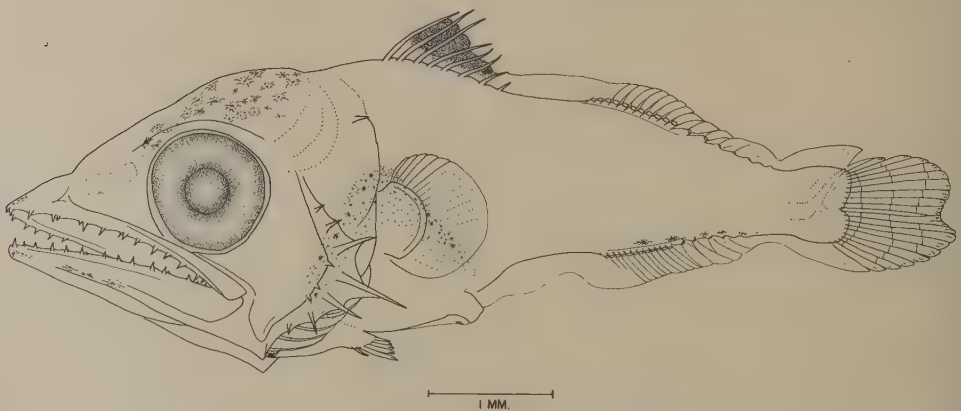

Figure 16. *Euthynnus yaito*, 7.6 mm.

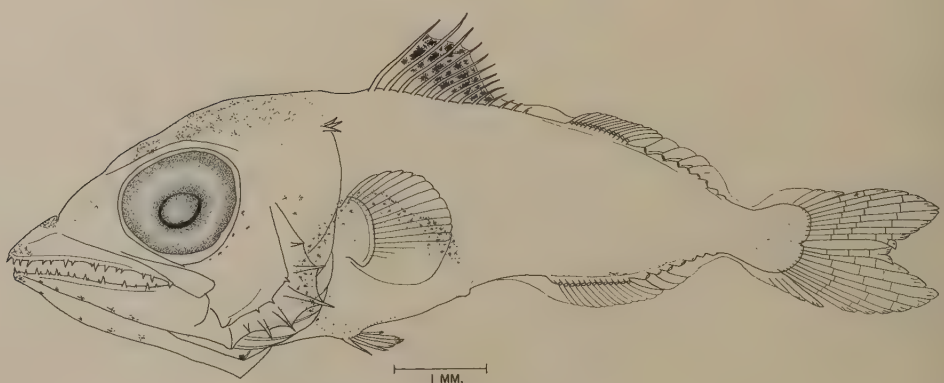

Figure 17. *Euthynnus yaito*, 9.6 mm.

4 additional chromatophores are present along the bases of the posterior end of the second dorsal fin a the first 3 dorsal finlets. These chromatophores are not yet developed on specimens below this size.

The third character is the number of myomeres or vertebrae. On all specimens below 8.0 mm. the my mere count is either 40 or 41. This compares well with the number of vertebrae (20 + 19 = 39) found stained specimens larger than 9.6 mm.

Finally, the larger specimens, 9.6 mm. and 12.2 mm., have 13 or more rays in both the second dors and anal fins.

Discussion of Species Differences.

The foregoing descriptions include certain consistent characters by which the three species of *Euthynnus* may be separated. Specimens larger than 9 or 10 mm. already show the adult complement of vertebrae. Using this character, it is possible to separate *lineatus*, which has 20 + 17 = 37 vertebrae, from both *yaito* and *alletteratus*, which have 20 + 19 = 39. Moreover, the number of rays in the second dorsal and anal fins of *lineatus* is consistently lower than in the other two species; *E. lineatus* normally has 11 or 12 rays in each fin, whereas *yaito* and *alletteratus* usually have 13 rays in the second dorsal and 13 or 14 rays in the anal fin. The separation of *lineatus* from the other two species is further aided by the fact that this species has been reported only from the Pacific Ocean off the western coast of North and Central America.

It would be easier to separate *alletteratus* from *yaito*, if the gill rakers were completely formed on juveniles and larvae. Since specimens smaller than 50 mm. do not have the full adult count, the separation of individuals below this size must be based on other criteria.

As far as is known, no adult *yaito* has ever been reported from the Atlantic Ocean and its adjoining bodies of water. *E. lineatus* is also not a possibility here, since this species has been reported only from the eastern Pacific. Therefore any *Euthynnus* larvae or juveniles taken from these waters are likely to be *alletteratus*. This supposition is supported by the extent of pigmentation on the head of the young. Our samples of *alletteratus* below 50 mm. are more heavily pigmented along the length of the upper and lower jaws than *yaito* of the same size.

In specimens smaller than 9 or 10 mm., the identifying characters are generally limited to body pigmentation. This does not mean, however, that the pigmentation peculiar to each species is restricted to this size group alone. On the contrary, these differences persist through specimens in the 25-mm. to 30-mm. group. Specifically, specimens of *yaito* and *lineatus* consistently bear fewer chromatophores along the lower jaw than comparable specimens of *alletteratus*. In *yaito* the lower jaw of the smallest specimen (4.6 mm.) has only 1 chromatophore, exclusive of those at the tip. The number of chromatophores increases to 5 in a 9.6-mm. specimen, and to about 8 in a 12.2-mm. specimen. In *lineatus*, the smallest specimen (5.0 mm.) has no chromatophores on the lower jaw. Between the 6.0-mm. and 21.0-mm. specimens the number of chromatophores increases from 3 to 8. For comparison, the smallest *alletteratus* examined (4.6 mm.) possesses 3 to 4 chromatophores on the lower jaw, and specimens between 5.5 mm. and 9.3 mm. have about 7 to 10 chromatophores which extend over nearly four-fifths the length of the lower jaw. A more striking difference is seen on the 12.0-mm. specimen, which has 2 rows of about 20 chromatophores in each row.

Another difference in pigmentation is seen in the row of chromatophores along the ventral margin of the body in the region of the anal fin and finlets. *E. yaito* and *lineatus* have 3 to 5 chromatophores, whereas *alletteratus* has from 6 to 11.

Despite the similarity in body pigmentation between *lineatus* and *yaito*, these two species can be separated by another character. The former species has either 38 or 39 myomeres, whereas the latter, as well as *alletteratus*, has 40 or 41.

It is interesting to note that in *Euthynnus* there are rarely any chromatophores along the midlateral and middorsal lines of the caudal peduncle. The only indication of such pigmentation occurs in specimens larger than 12 mm. in the case of *alletteratus*, and in specimens larger than 18.6 mm. in the case of *lineatus*. The largest *yaito* examined (12.2 mm.) does not show any pigmentation in these areas. Although these characters have no bearing on the separation of the *Euthynnus* species, they must be considered, not only because they are important in differentiating this genus from *Auxis*, but because our descriptions of *Euthynnus* differ from the previously published reports of Ehrenbaum (1924) and Wade (1949).

Ehrenbaum (1924) separates *Euthynnus* from *Auxis* mainly on the appearance of the first dorsal fin. He states that in *Auxis* the fin membrane posterior to the ninth ray (spine) becomes lower and is usually gone in specimens of 11 mm. to 12 mm. in length; and that in *Euthynnus* it (the fin membrane) continues at a similar height to the second dorsal, and, when stained, 6 very obscure rays seem to appear on it, thus bringing the total rays to 15.

Examination of the specimens at hand shows that the fin membrane between the last spine of the f dorsal and the origin of the second dorsal fin is still present on a 15.5-mm. *Auxis*, and that the height of fin membrane varies widely among specimens of the same species. It is believed that the variation in t character is mainly an artifact caused by preservation and is unreliable in separating the larvae of th two species.

Ehrenbaum's separation of *Euthynnus* based on the number of spines in the first dorsal fin seems to in error. The "6 very obscure rays" which he mentions in describing *Euthynnus* are clearly noticeable our specimens of *Auxis* measuring between 9.7 mm. and 50.0 mm. These rays or spines are most pro nent on specimens measuring between 11 mm. and 15 mm., and they gradually become inbedded bene the outer layer of skin in larger juveniles. Schaefer and Marr (1948) also noticed these subcutaneous spi on their juvenile *Auxis*.

Further observations on the number of first dorsal spines relative to body length of the two species a add to the doubt of Ehrenbaum's separation. The dorsal fin spine count of Ehrenbaum's *alletteratus* dif from that of our 3 species of *Euthynnus*. In his figures of *alletteratus*, he shows 6 spines in the first do fin of an 8.6-mm. specimen, and about 9 spines in a 10.1-mm. specimen. In our material, however, 3 species of *Euthynnus* between 7 mm. and 8 mm. already have 7 to 9 spines, and specimens between 9 m and 10 mm. have 12 to 15 spines. All our specimens above 10 mm. have 15 to 16 spines, which correspo to the total count of the adult *Euthynnus*. Ehrenbaum's lower counts, on the other hand, agree with counts on *Auxis*. Our *Auxis* larvae between 7 mm. and 8 mm. in length have 6 to 8 spines in the first do fin, and those between 9 mm. and 11 mm. have 9 spines, only 1 or 2 spines less than the full adult co plement. The latter count of 9 spines is identical with Ehrenbaum's 10.1-mm. specimen, which he designa as *E. alletteratus*.

Differences in pigmentation are also noticeable. Ehrenbaum reports that *Euthynnus* has 1 to 3 ch matophores along the bases of the anal finlets and sometimes a single chromatophore at the base of last dorsal finlet. In the present study the specimens designated as *Euthynnus* in no case bear any chroma phore at the base of the last dorsal finlet. On the contrary, this pigmentation normally appears on specim having fewer spines in the first dorsal fin, that is, on specimens designated here as *Auxis*. Furthermo Ehrenbaum's descriptions of *Euthynnus* give no indication of pigmentation on the first dorsal fin. In c trast with this, our specimens show very noticeable pigmentation on this fin as early as 7.1 mm., and entire fin is completely pigmented at 12 mm. This pigmentation persists even on specimens as large as 58-mm. *alletteratus* figured here (fig. 14). Schaefer and Marr's (1948) descriptions of juvenile *linea* and Wade's (1950) descriptions of juvenile *yaito* also show the first dorsal fin as being heavily pigment

Wade (1951) describes the larvae of *yaito* as having 3 distinct rows of chromatophores in the region the caudal peduncle, and like Ehrenbaum's description, his illustration of the 10.5-mm. specimen sho only 8 spines in the first dorsal fin. In contrast with this, our *yaito* at 9.6 mm. has 13 spines in first dorsal fin, and the chromatophores in the caudal region are present only along the midventral l of the body.

On the basis of these observations the author believes that the larval *Euthynnus* of Ehrenbaum (19 and of Wade (1951) should be designated as *Auxis*.

GENUS *AUXIS*

Notes on Adults and Juveniles.

It is generally accepted that there are two forms of *Auxis*. These can be separated from each other mai by a difference in corselet development. The corselet is a plaque of scales on the anterior part of the bo in the form of 3 wedges, whose apices point posteriorly (fig. 18). The dorsal wedge begins near the tip the pectoral fin, halfway between the lateral line and the dorsal edge of the body. The outline trails p

riorly, rising toward the origin of the second dorsal fin. From the anterior end of the dorsal wedge, the orsal profile of the middle extension of the corselet trails posteriorly and ventrally toward the lateral line nd meets its complement which begins near the angle of the opercle and rises obliquely toward the lateral ne. The lower wedge begins near the angle of the opercle and trails ventrally toward the tip of the ventral ns. Variations in the length of the corselet occur only in the middle branch which roughly follows the teral line; hence the term corselet as used in this paper shall refer to this middle extension.

One form of *Auxis*, specifically known as *thazard* (Lacépède, 1802), is characterized by a short corselet hich narrows abruptly a little past the tip of the pectoral fin and extends posteriorly only to about midway etween the origins of the first and second dorsal fins. t the level of the second dorsal origin, the corselet sually is only one scale-row wide. The second form *Auxis* is characterized by a long, gradually tapering orselet which extends to, and in many instances goes eyond, the base of the second dorsal finlet. The corselet 9 to 18 scale-rows wide below the origin of the second orsal fin on specimens 195 mm. to 200 mm. in total ngth.

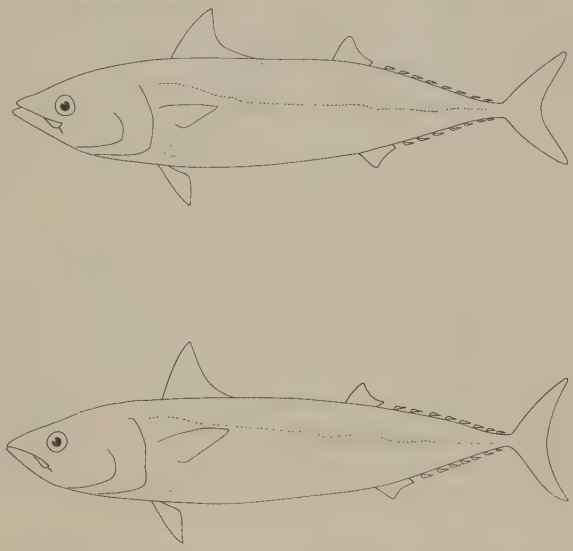

Figure 18. Sketch of *Auxis* showing corselet formation.

The nomenclature of the long-corseletted form is ther confused. For many years, the name *tapeinosoma* LEEKER was ascribed to such specimens taken in the hilippine waters. After studying Bleeker's (1854) escription of *tapeinosoma*, the author has come to the onclusion that this is not the long-corseletted form. LEEKER describes *tapeinosoma* as having a corselet hich "ends slightly posterior to the pectoral fins". ost of the other characters he mentions agree more osely with specimens of *thazard*, than they do with ecimens of the Philippine long-corseletted form. Furthermore, through correspondence with John E. ITCH, California Department of Fish and Game, who examined the type specimen of *tapeinosoma*, the author arned that Bleeker's fish is definitely the short-corseletted form. Bleeker's (1855) description of a ecimen from Ternate, East Indies, which he named *A. thynnoides*, seems to be the long-corseletted form. e describes this fish as having a corselet which "ends far behind the pectoral fin". Thus, the long-corse-tted *tapeinosoma* of Wade (1949) and of Herre and Herald (1951) appears to be a misnomer and will e called *A. thynnoides* Bleeker in this paper.

In addition to the differences in corselet breadth and length, Wade (1949) and Herre and Herald 1951) point out that *thazard* in the western Pacific normally has fewer gill rakers than *thynnoides* (see table 3). lead (1951) also mentions the low gill raker counts on the eastern Pacific *thazard* taken off the coast f Central America. Godsil (1954), however, reports that his *thazard* (all of which definitely possessed the ort corselet), which were taken off Baja California and the Galapagos Islands, have high gill raker counts milar to those of *thynnoides* described by Wade (1949) and Herre and Herald (1951). It therefore ap-ears as though the number of gill rakers, by itself, may not be a reliable character in differentiating the vo forms of *Auxis*.

The distribution of the two forms of *Auxis* in the Atlantic is also in a confused state with contradictory iews being held by various investigators. Herre and Herald (1951), who are aware of the differences etween *thazard* and *thynnoides*, recognized Atlantic *thazard*, but Fitch (private correspondence), who has lso examined Atlantic *Auxis*, is of the opinion that no *thazard* occurs there, and that the Atlantic form is ot separable from the western Pacific long-corseletted form. The author has examined a 287-mm. specimen f *Auxis* from Woods Hole, Massachusetts, which is presently deposited in the United States National luseum. This specimen has the long corselet typical of *thynnoides*. A review of the literature shows that

Table 3. Gill raker counts of *Auxis* obtained by various investigators.

	Number of gill rakers	*Auxis thazard*					*Auxis thynnoides*	
		Philippine[1]	Hawaii[2]	Central America[3]	Baja California[4]	Atlantic[5]	Philippine[1]	Hawai
Upper limb	7	3	–	2	–	–	2	–
	8	2	–	2	–	3	2	–
	9	77	–	3	–	12	5	–
	10	109	8	2	4	7	99	14
	11	1	2	–	1	–	103	6
	12	–	–	–	–	–	5	–
Angle of arch	1	212	10	9	4	22	216	20
Lower limb	27	4	–	1	–	–	–	–
	28	40	–	–	–	–	–	–
	29	74	1	3	–	–	–	–
	30	59	5	2	–	5	–	–
	31	28	2	2	1	4	1	–
	32	5	1	1	–	6	19	4
	33	–	1	–	3	6	53	2
	34	–	–	–	–	1	79	10
	35	–	–	–	1	–	42	2
	36	–	–	–	–	–	19	2
	37	–	–	–	–	–	3	–
Total gill rakers	36	–	–	1	–	–	–	–
	37	2	–	–	–	–	–	–
	38	17	–	1	–	–	–	–
	39	47	–	1	–	1	–	–
	40	66	5	2	–	2	–	–
	41	42	3	1	–	7	2	–
	42	32	1	1	1	3	2	–
	43	6	1	1	–	5	14	3
	44	–	–	1	2	4	40	2
	45	–	–	–	2	–	57	9
	46	–	–	–	–	–	51	3
	47	–	–	–	–	–	31	2
	48	–	–	–	–	–	13	1
	49	–	–	–	–	–	3	–
	50	–	–	–	–	–	3	–
Number of specimens		212	10	9	5	22	216	20

[1] WADE, 1949; HERRE and HERALD, 1951.
[2] MATSUMOTO, 1958b.
[3] MEAD, 1951.
[4] GODSIL, 1954.
[5] HERRE and HERALD, 1951.

most of the descriptions of *Auxis* from the Atlantic do not mention the corselet. Nearly all of these pap however, refer to the figure of *thazard* given by JORDAN amd EVERMANN (1900), which definitely sh the long corselet as in *thynnoides*. It is possible that HERRE and HERALD (1951) and FITCH (private corres dence) examined different forms of *Auxis*, and that the two types of *Auxis* may be present in the Atla

Two forms of *Auxis* were known to occur in both the eastern and western parts of the Pacific, but u recently only one (*thazard*) was known from the central Pacific area. On November 30, 1957, 21 long- seletted specimens were captured by pole-and-line fishing in the Hawaiian Islands from the United St Fish and Wildlife Service' research vessel, "John R. Manning". These specimens were found to be iden (MATSUMOTO, 1958b) with the Philippine long-corseletted form described by WADE (1949).

It is interesting to note that both long- and short-corseletted forms taken in Hawaiian waters were f the same school. Through correspondence with DR. S. JONES, Chief Research Officer at the Central Ma Fisheries Research Station, Mandapam Camp, South India, it was learned that two types of *Auxis* also o in the Indian Ocean, and that they are frequently found together in the same school. Similar observat were also reported by KISHINOUYE (1915).

The separation of juveniles of these two forms imposes a difficult problem, since the most reliable c acter upon which the separation of the adults is accomplished (corslelet morphology) does not appear

ıe fish are about 200 mm. in fork length. Gill raker counts are of limited aid also, since this character is nly applicable to fish taken from certain localities where the two forms exhibit extreme counts.

The larvae, however, seem to show some variation in pigmentation, and because there is a possibility ıat this variation may be associated with the two forms of *Auxis*, two separate series of larvae are described ı this study. These series are designated as types I and II, and the validity of their separation is discussed ıter in this report.

Descriptions of Larvae and Postlarvae.

The descriptions of *Auxis* are based on an examination of 2,195 specimens (1,425 type I; 770 type II) aken by various Danish vessels, principally the "Dana". Of this number 63 larval specimens from the ıtlantic and 76 from the Pacific were studied in detail. In addition, 50 juveniles from the Gulf of Mexico anging in length from 20 mm. to 84 mm. were examined and compared to Wade's collection of 21 *A. thazard* nd 15 *A. thynnoides* between 40 mm. and 238 mm. from Philippine waters.

Auxis type I.

Type I is represented by a series of larvae which resembles the form described in a previous paper (Matsumoto, 1958a). It was stated then that the series belonged to the genus *Auxis* mainly on the basis of 1) two or more rows of chromatophores in the region of the caudal peduncle, (2) the pigmented spot at the ymphysis of the pectoral girdle, (3) the relatively small number of spines (less than 9 or 10) in the first loral fin, and (4) the paucity of chromatophores in the first dorsal fin. The species was designated tentatively ıs *thazard*, inasmuch as many of the specimens were taken in Hawaiian waters, where adults of only *A. thazard* were then known to occur regularly. Part of the material used in that paper was taken on one of the "Dana" cruises, and most *Auxis* figures were drawn from these specimens. The original illustrations ıre reproduced here as figures 19 to 23.

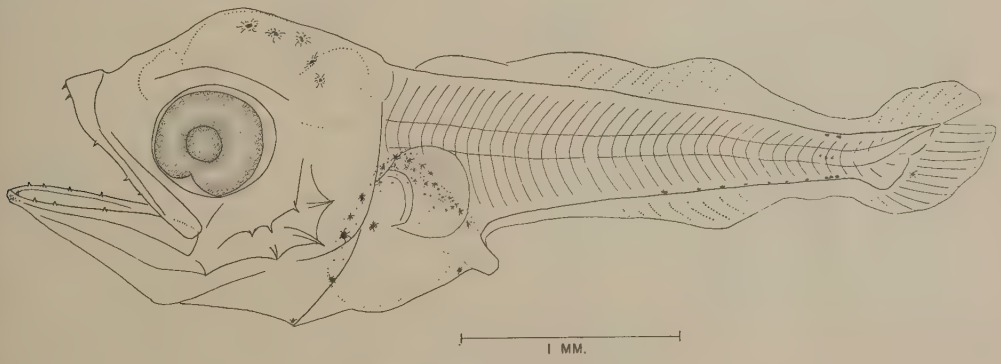

Figure 19. *Auxis* type I, 4.5 mm.

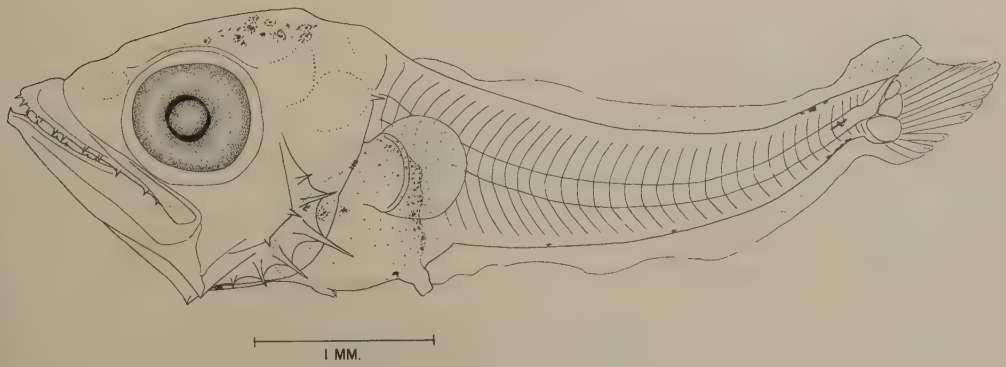

Figure 20. *Auxis* type I, 5.5 mm.

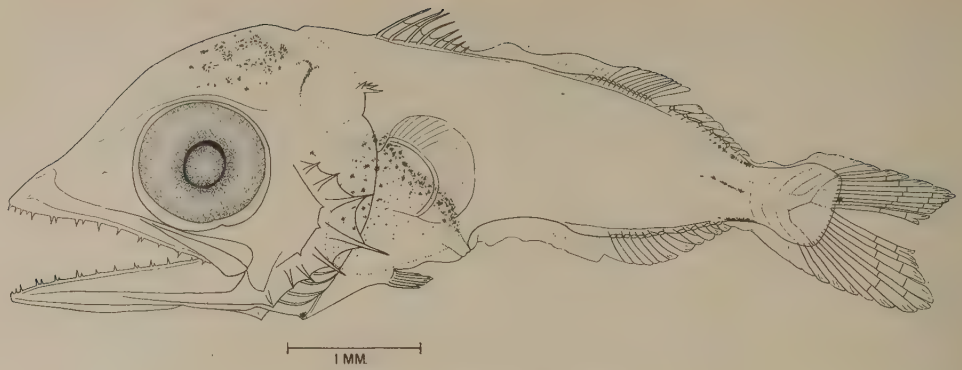

Figure 21. *Auxis* type I, 7.05 mm.

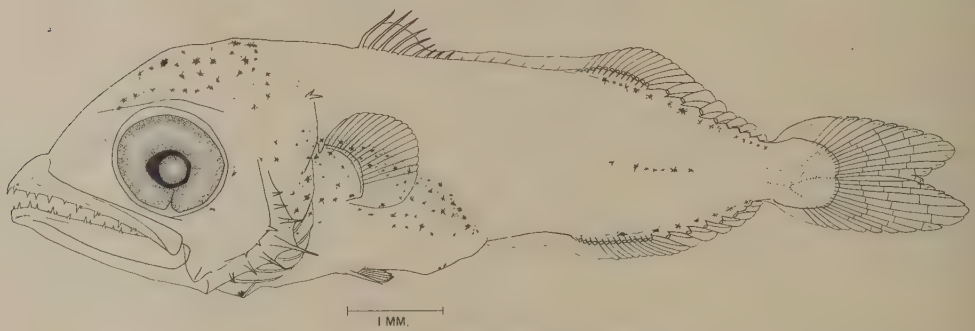

Figure 22. *Auxis* type I, 9.7 mm.

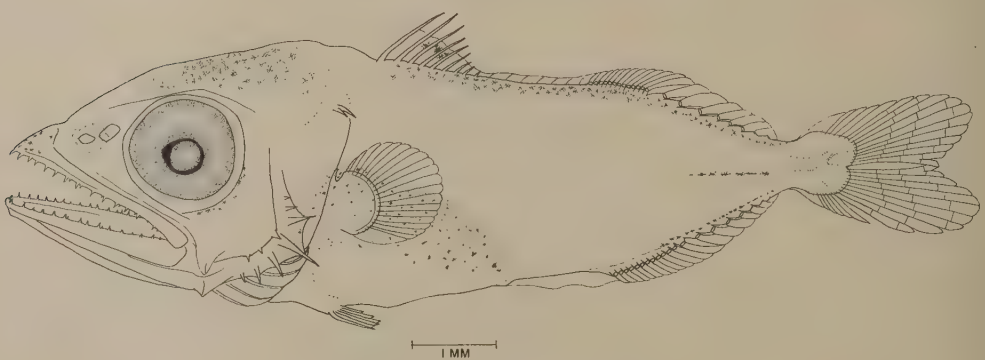

Figure 23. *Auxis* type I, 11.2 mm.

It is needless to repeat all the details of description for type I. Instead, a resumé of the more import characters mentioned above follows:

(1) *Two or more rows of chromatophores in the region of the caudal peduncle.* In this particular series, ev the smallest specimen, 4.5 mm. (fig. 19), has 3 distinct rows of close-set chromatophores along the m dorsal, midlateral, and midventral lines of the caudal peduncle. The chromatophores increase in numb with growth of the fish, and by the time the species has attained 11.2 mm. (fig. 23) 1 or 2 rows of chroma phores are present along the dorsal midline of the body from the origin of the first dorsal fin to the cau peduncle. The number of chromatophores along the midlateral line also increases, and in a 13.2-m specimen (fig. 24) the chromatophores have moved internally toward the vertebral column. At about 14.0 m a single row of dermal chromatophores is seen along the midlateral line slightly posterior to the tip of t

ctoral fin. This row gradually increases in width and length until it appears as a wide, dark band, which distinctly noticeable in the 25-mm. specimen (fig. 25).

(2) *Pigment spot at the symphysis of the pectoral girdle.* This spot, common to both *Auxis* and *Euthynnus*, present in nearly all of the specimens examined. It usually consists of a single large chromatophore in ecimens below 20 mm. In larger specimens, however, this spot may be represented by 2 to 4 small, closely ouped chromatophores.

(3) *Number of spines (less than 9 or 10) in the first dorsal fin.* The first dorsal spines are insufficiently veloped for comparative purposes in specimens below 7 or 8 mm. The 9.7-mm. specimen (fig. 22), how-

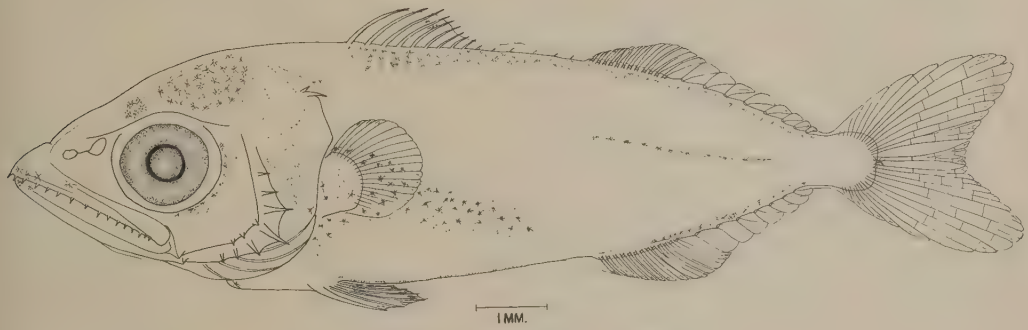

Figure 24. *Auxis* type I, 13.2 mm.

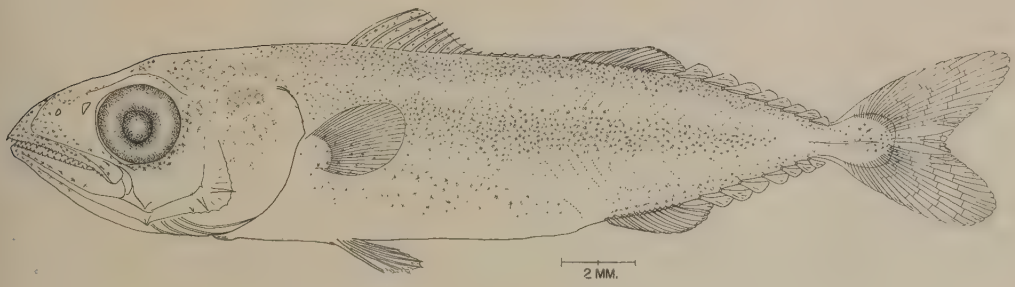

Figure 25. *Auxis* type I, 25.0 mm.

ver, possesses a first dorsal fin composed of 9 well-developed spines which closely resemble that of the adult. he first and second dorsal fins are widely spaced, and the initial development of 7 additional small spines re noticed between the end of the first and the origin of the second dorsal fins. These spines do not develop any great length, as noticed in the 25-mm. specimens, but are still distinctly noticeable on larger juveniles p to about 50 mm. Except for the anterior 2 or 3 spines, which later develop as part of the first dorsal fin f the adult, these inter-dorsal spines ultimately become inbedded beneath the outer layer of skin.

(4) *Number of chromatophores in the first dorsal fin.* Generally, the first dorsal fin of juvenile *Auxis* in very ghtly pigmented and is almost colorless. The first signs of pigmentation on this fin appear rather late, at bout 11.0 mm., and the 11.2-mm. specimen illustrated here has only 3 large chromatophores. The 13.2-mm. pecimen also shows few chromatophores. Beyond this size the number of chromatophores seems to increase with growth, but at no stage is this pigmentation conspicuous. The chromatophores themselves are cattered almost evenly throughout the fin membrane, as shown in the 25.0-mm. specimen (fig. 25).

luxis type II.

Type II refers to a series of larvae, measuring from 3.5 mm. to 7.2 mm., which lack chromatophores long the midlateral line in the caudal peduncle region. This lack, however, is not always consistent, and n some specimens chromatophores are missing on one side only. The smallest specimen (fig. 26) has a single

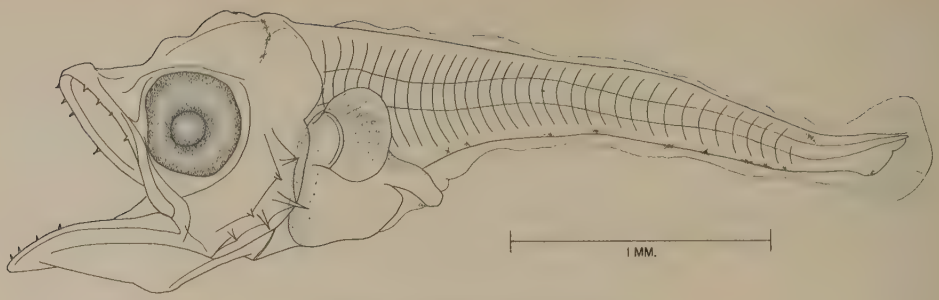

Figure 26. *Auxis* type II, 3.5 mm.

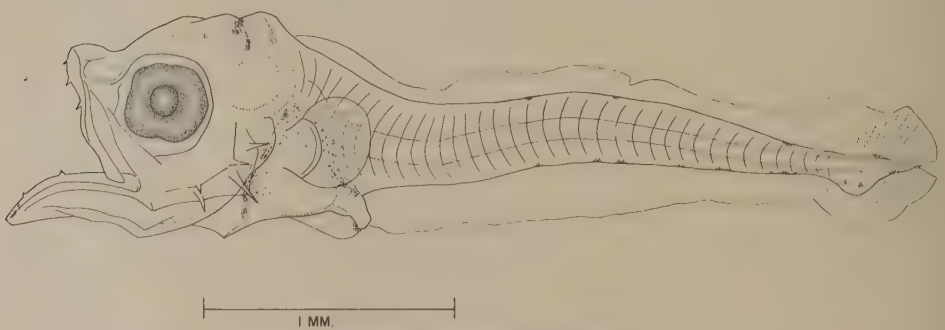

Figure 27. *Auxis* type II, 3.7 mm.

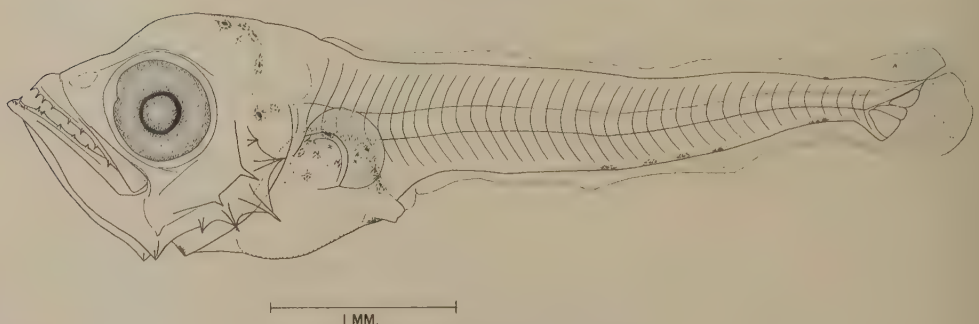

Figure 28. *Auxis* type II, 5.2 mm.

darkly pigmented spot at the symphysis of the pectoral girdle and chromatophores on both the dorsal ventral edges of the body in the caudal peduncle region. Unlike the type I specimens, only one chromatoph is present on the dorsal midline of the caudal peduncle region. A long series of 9 well-spaced chrom phores is present along the entire ventral margin of the body. The midbrain is sparsely pigmented and midsection of the lower jaw has no pigmentation. The myomere count is identical with that found in typ

The 3.7-mm. specimen (fig. 27), which was earlier identified as *A. thazard* (?) (Matsumoto, 195 appears similar to the 3.5-mm. specimen and has therefore been placed in this series.

A slightly larger specimen, 5.2 mm. (fig. 28), also has the same characteristics as the 3.5-mm. specin except for the pigmentation on the posterior part of the body. There are 3 very closely spaced chrom phores on the midventral line of the caudal peduncle region, and 4 more widely spaced chromatoph farther forward.

Several changes occur in the 7.2-mm. specimen (fig. 29). The first dorsal fin consists of 5 spines, and second dorsal fin is represented by about 11 rays. The anal fin also shows signs of development, and a

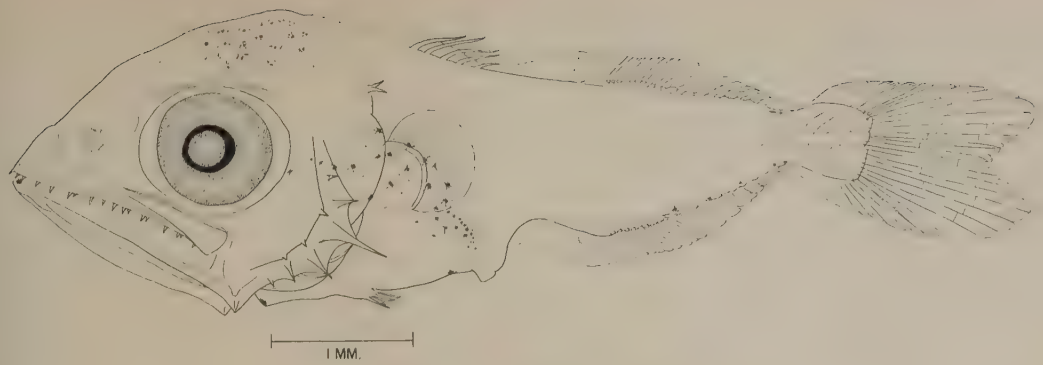

Figure 29. *Auxis* type II, 7.2 mm.

rays can be distinguished. The anal finlets, like their dorsal counterparts, are hardly noticeable. The audal fin is quite advanced in development, and its posterior margin is beginning to fork. The ventrals are resent, but they are still very small.

In general only minor changes in pigmentation are evident. Two very close-set chromatophores are resent on the dorsal edge of the caudal peduncle, and 2 more similar ones are noticeable opposite them n the ventral edge. Anteriorly, 3 more well-spaced chromatophores are present along the bases of the nal finlets.

The series stops at about 8 mm., and all specimens above this size are referable to type I.

Discussion of Species Differences.

The two series of *Auxis* just described show minor differences only, the most obvious being the variation n pigmentation in the caudal peduncle region of specimens up to 8 mm. in total length. In type I there enerally are 3 equally developed rows of pigment. In type II the middorsal edge of the caudal peduncle isually contains only one or two chromatophores, whereas the midlateral line has none. The midventral ine of both series contains a group of 2 to 3 close-set chromatophores at the caudal peduncle and 3 to 6 vell-spaced chromatophores farther forward. In specimens larger than 8.0 mm. the 3 rows of pigment seen n type I extend anteriorly with increasing numbers of chromatophores. Type II larvae of comparable sizes were not observed, and it is believed that both types assume a similar external appearance above this size.

One important observation which must be mentioned here is the extreme inconsistency of pigmentation on the midlateral line. In many specimens there are 1 to 5 chromatophores on one side of the body, but none on the other side. Such a wide variation in pigmentation between the two sides of the same fish enders the separation of *Auxis* into types I and II rather doubtful.

Judging on the basis of this, and also on the fact that the type II series stopped at about 8 mm., one nay conclude that the two types are merely variants of a single species.

GEOGRAPHICAL DISTRIBUTION OF *EUTHYNNUS* AND *AUXIS* LARVAE

In spite of the wealth of larval and postlarval tunas taken by the "Dana" and other Danish vessels, his material was not treated quantitatively for several reasons. First, measurements of the volume of water strained by the sampling nets were not available; second, several types and sizes of nets were used in collecting the samples; third, the tows were all made with open nets which were hauled horizontally for engths of time ranging from 5 minutes to 4 hours; and fourth, the number of levels at which the nets were

towed generally varied from station to station, and the maximum depths, or more correctly, the maxim lengths of wire let out, also varied from 100 to 5,000 meters at different station. Thus, the distributio the larvae can also be treated only qualitatively.

An examination of reports describing adult *Euthynnus* leads one to the conclusion that these fish norm live closer to land masses than other tunas. Our own observations on numerous POFI cruises in the cen Pacific area seem to bear this out.

This association of adult *Euthynnus* with land masses is also seen, though to a lesser extent, in the c tures of larvae and postlarvae in the Atlantic and Pacific Oceans. Figure 30 shows the positions wh

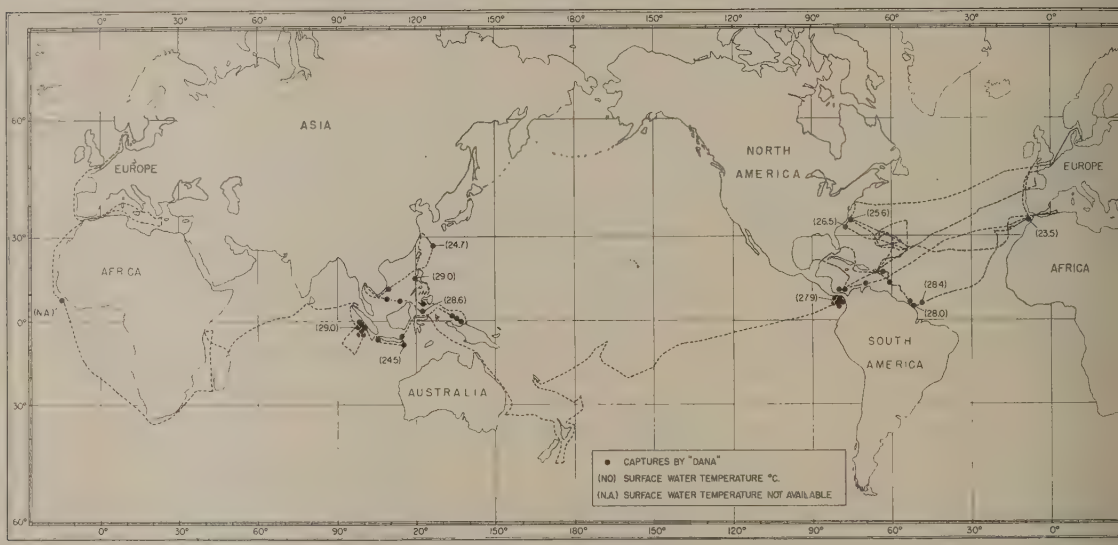

Figure 30. Localities of capture of *Euthynnus* larvae by the "Dana".

these larvae were taken on the several cruises in 1920–22 and 1928–30 by the "Dana" (*see* Appendix ta for station positions and numbers of larvae taken). Larval *Euthynnus* were taken in the Caribbean S off the east coast of North America, off the coast of South America, in the Gulf of Panama, in the I Indies Archipelago, and off the west coast of Africa. Except for the few stations west of Sumatra, no samp from the Indian Ocean were available to us. It is interesting to note that no *Euthynnus* larva was taken midocean, although there were numerous stations across both the Atlantic and Pacific Oceans. The farth station from land at which a *Euthynnus* larva was recognized was about 300 miles; not a great distance far as the fast-swimming adults are concerned.

This is somewhat in contrast with the author's observations for *Katsuwonus pelamis* and *Neothun macropterus* larvae in the Pacific (Matsumoto, 1958a). Numerous larvae of these two species were ta in the equatorial current systems at midocean stations as well as at stations close to land masses.

Figure 30 also shows the extremes in surface water temperatures in which *Euthynnus* larvae were tak In the western Atlantic these larvae were taken at water temperatures which ranged from 25.6°C. to 28.4 Temperatures from the two eastern Atlantic stations which yielded *Euthynnus* larvae were not availa However, at one station, 6 miles east of that shown near the northwest coast of Africa, the temperature 23.5°C. In the Indo-Pacific area larvae were taken at water temperatures ranging from 24.5°C. to 29.0 Although there is no assurance that these values truly represent the lower and upper limits of temp tures tolerated by the young of *Euthynnus*, they at least give us an idea of the wide temperature ra throughout which these larvae can exist.

The captures of *Auxis* larvae (fig. 31) indicate a slightly different distributional pattern. Although n of the larvae were taken in the same areas where *Euthynnus* larvae were captured, one individual

cognized in the catch from a midocean station in the Atlantic, approximately 1,200 miles from the nearest nd mass. Comparable midoceanic catches were noted in the Pacific (Matsumoto, 1958a), where one larva as recorded from 1°42′ north latitude and 130°22′ west longitude, and another larva from 7° north latide and 140° west longitude, approximately 800 and 900 miles, respectively, from the nearest land mass. om these midoceanic captures it can be surmised that *Auxis* is a more pelagic form than *Euthynnus*.

Figure 31 also shows the extremes in water temperatures in which *Auxis* larvae were taken. In the estern Atlantic this range is comparable to that in which *Euthynnus* larvae were taken. The lowest temrature (23.3°C.) which yielded *Auxis* larvae was in the eastern Atlantic near the northwest coast of

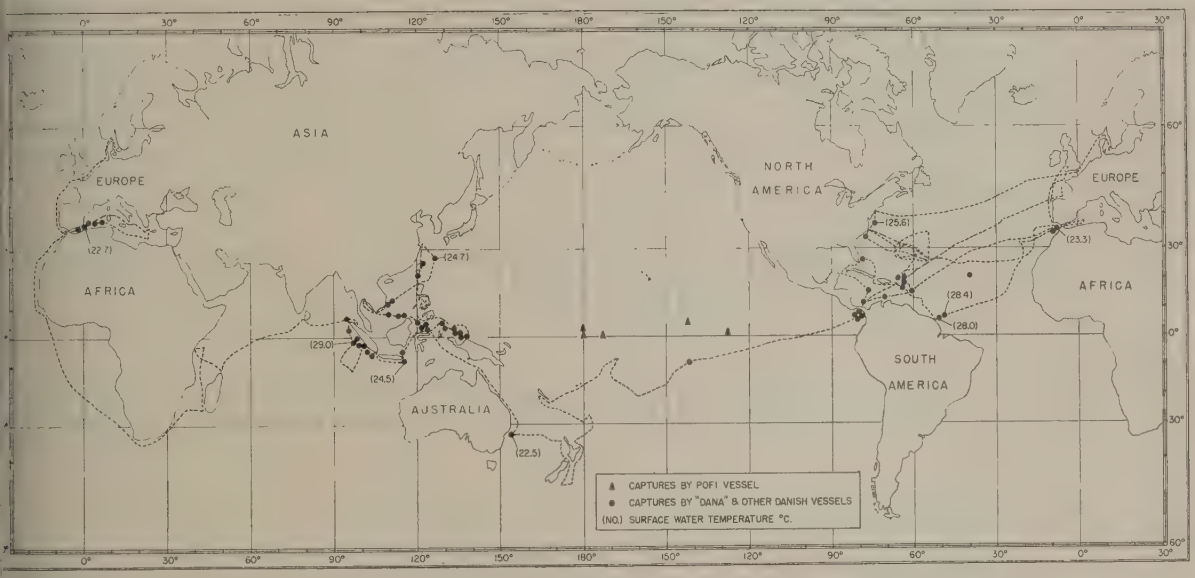

Figure 31. Localities of capture of *Auxis* larvae by the "Dana" and POFI vessel.

frica. In the Indo-Pacific area, water containing *Auxis* larvae ranged from 22.5°C. to 29.0°C., the coldest ater having been registered off the eastern coast of Australia.

Although this bit of information is interesting and may suggest that *Auxis* larvae are able to withstand older water than *Euthynnus* larvae, the amount of data available does not justify the formation of any eliable conclusion.

SPAWNING AREAS AS INDICATED BY LARVAL CATCHES

A large portion of the larvae of *Euthynnus* and *Auxis* consisted of recently hatched individuals measuring mm. to 4 mm. Although many of these were recognized to genus, they were not positively identified to pecies. Because of this, only general statements are attempted here.

In a previous paper (Matsumoto, 1958a), it was hypothesized that recently hatched larvae of *K. pelamis* nd *N. macropterus* measure approximately 3 mm.; that the larvae in this stage, like the eggs which precede hem, are planktonic, their displacement from the spawning site being due to ocean currents alone; and that xcept in a few areas with exceptionally strong currents, this displacement is relatively insignificant. It was herefore believed that the localities where larvae of this size occurred represented the actual spawning sites. f we extend this reasoning to include larvae of *Euthynnus* and *Auxis*, on the assumption that the emryonic development of these species is similar to that of *K. pelamis* and *N. macropterus*, certain deductions an be made about their spawning areas.

Judging from the localities in which the adults and larvae of *Euthynnus* were taken, it may be said t this genus spawns in the vicinity of land masses. The same may be said of *Auxis*; but because its spa ing sites also include oceanic situations, as indicated by larval capture in the middle of the Atlantic and much as 900 miles from land in the Pacific (fig. 31), *Auxis* may be considered a more pelagic spawner t *Euthynnus*.

SUMMARY

1. Larvae and postlarvae of three species of *Euthynnus* (*E. alletteratus*, *E. lineatus* and *E. yaito*) and forms of *Auxis* are described. Most of the material was collected by various Danish vessels, notably research vessel "Dana" during an extended cruise in the North Atlantic and the Gulf of Panama fr 1920–22, and during the round-the-world cruise from 1928–30. Other material included juveniles *Euthynnus* and *Auxis* collected by various organizations from the Gulf of Mexico, the Pacific waters off Cen America, and the Philippine waters.

2. Two types of *Auxis* larvae were noted in the samples. However, in the absence of conclusive evide it was hypothesized that the two types represented variations of the same species.

3. *Euthynnus* larvae were generally found in waters closer to land masses than larvae of other spe of tunas.

4. The bulk of *Auxis* larvae was also found close to land, but captures in the middle of the Atlantic up to 900 miles from land in the Pacific indicated that this genus spawns farther away from land t *Euthynnus*.

5. The presence of recently hatched larvae in the catches indicated that the locality of capture wa the vicinity of the spawning sites of these fishes.

LITERATURE CITED

LEEKER, PIETER. 1854. Faunae ichthyologicae japonicae species novae. Natuurkundig Tijdschrift voor Nederlandsch-Indie uitgegeven door de Naturekundige Vereenigining in Nederlandsch-Indie, 6: 408–409.

— 1855. Vijfde bijdrage tot de kennis der ichthyologische fauna van Ternate. Natuurkundig Tijdschrift voor Nederlandsch-Indie uitgegeven door de Naturekundige Vereenigining in Nederlandsch-Indie, 8: 301.

ROCK, VERNON E. 1954. Some aspects of the biology of the aku, *Katsuwonus pelamis*, in the Hawaiian Islands. Pacific Science 8(1): 94–104.

ANTOR, T. E. 1850. Catalogue of Malayan fishes. Journal of the Royal Asiatic Society of Bengal 18: 983–1042.

HRENBAUM, ERNST. 1924. Scombriformes. Rept. Danish Oceanogr. Exped. 1908-1910 to the Mediterranean and Adjacent Seas, No. 8, 2 (Biology), A. 11: 42 pp.

RASER-BRUNNER, A. 1949. On the fishes of the genus *Euthynnus*. Annals and Magazine Natural History, Series 12, 2(20): 622–628. London.

— 1950. The fishes of the family Scombridae. Annals and Magazine Natural History, Series 12, 3(26): 131–163.

ODSIL, HARRY C. 1954. A descriptive study of certain tuna-like fishes. California Division Fish & Game, Fish Bull. 97, 185 pp., 93 figs.

ERRE, ALBERT W., and EARL S. HERALD. 1951. Noteworthy additions to the Philippine fish fauna with descriptions of a new genus and species. Philippine Jour. Science, 79(3): 309–340.

VINE, F. R. 1947. The fishes and fisheries of the Gold Coast. The Crown Agents for the Colonies, 352 pp. London.

ORDAN, DAVID S., and BARTON W. EVERMANN. 1900. The fishes of North and Middle America. Bull. U. S. National Museum, 47(Part 4): 3137–3313, 392 pls., 958 figs.

ISHINOUYE, KAMAKICHI. 1915. A study of the mackerels, cybiids, and tunas. Suisan Gakkai Hō, 1(1): 1–24. (*In* U.S. Department of the Interior, Fish and Wildlife Service, Special Scientific Rept.: Fisheries No. 24, pp. 1–14, 1950. Translated from the Japanese by W. G. Van Campen).

— 1920. Mexican little tunny. Suisan Gakkai Hō, 3(2): 113.

IPMAN, HARRY J. 1935. Staining the skeleton of cleared embryos with alizarin red S. Stain Technology, 10(2): 61–63.

[ATSUMOTO, WALTER M. 1958a. Description and distribution of larvae of four species of tunas in central Pacific waters. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 58 (128): 31–72.

— 1958b. Notes on the Hawaiian frigate mackerel, genus *Auxis*. (MS approved for publication by Washington).

[EAD, GILES W. 1951. Postlarval *Neothunnus macropterus*, *Auxis thazard*, and *Euthynnus lineatus* from the Pacific coast of Central America. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 52(63): 121–271.

[URPHY, GARTH I., and RICHARD S. SHOMURA. 1953a. Longline fishing for deep-swimming tunas in the central Pacific, 1950–51. U. S. Department of the Interior, Fish and Wildlife Service, Special Scientific Rept.: Fisheries No. 98, 47 pp.

— 1953b. Longline fishing for deep-swimming tunas in the central Pacific, January-June 1952. U. S. Department of the Interior, Fish and Wildlife Service, Special Scientific Rept.: Fisheries No. 108, 32 pp.

— 1955. Longline fishing for deep-swimming tunas in the central Pacific, August–November 1952. U. S. Department of the Interior, Fish and Wildlife Service, Special Scientific Rept.: Fisheries No. 137, 42 pp.

[IVAS, LUIS R. 1951. A preliminary review of the western North Atlantic fishes of the family Scombridae. Bulletin of Marine Science of the Gulf and Caribbean, 1(3): 209–230.

ANZO, LUIGI. 1932a. Uova e primi stadi larvali di *Pelamys sarda* Cuvier & Valenciennes. R. Comitato Talassografico Italiano, Mem. 188, 10 pp.

— 1932b. Uova e primi stadi larvali di tonno (*Orcynus thynnus* Ltkn.). R. Comitato Talassografico Italiano, Mem. 189, 16 pp.

— 1933. Uova e primi stadi larvali di alalonga (*Orcynus germo* Ltkn.). R. Comitato Talassografico Italiano, Mem. 198, 9 pp.

CHAEFER, MILNER B., and JOHN C. MARR. 1948. Juvenile *Euthynnus lineatus* and *Auxis thazard* from the Pacific Ocean off Central America. Pacific Science, 2(4): 262–271.

CHMIDT, JOHANNES. 1929. The Danish "Dana"-Exped. 1920–22, No. 1.

ÅNING, Å. VEDEL. 1934. Carlsberg Foundation's oceanographical expedition round the world 1928–30. Dana-Report No. 1, 130 pp.

— 1944. Carlsberg Foundation's oceanographical expedition round the world 1928–30. Dana-Report No. 26, 15 pp.

WADE, CHARLES B. 1949. Notes on the Philippine frigate mackerels, family Thunnidae, genus *Auxis*. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 51(46): 229–240.

— 1950. Juvenile forms of *Neothunnus macropterus*, *Katsuwonus pelamis*, and *Euthynnus yaito* from Philippine Seas. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 51(53): 395–404.

— 1951. Larvae of tuna and tuna-like fishes from Philippine waters. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 51(57): 445–485.

APPENDIX

The following tables list by species the number of larvae collected by Danish vessels from 1920 to 1937. Only stations at which *Euthynnus* or *Auxis* larvae were taken are included in the tables. Additional hydrographic formation at each of the stations may be obtained from *the Danish "Dana"-Expeditions 1920–22*, No. 1 (SCHM 1929); *Introduction to the Reports from the Carlsberg Foundation's Oceanographic Expedition Round the World 1928* Dana-Report No. 1, (TÅNING, 1934); and *List of Supplementary Pelagic Stations in the Pacific Ocean and the Atla* Dana-Report No. 26, (TÅNING, 1944).

Appendix **Table 1.** Record of *Euthynnus* captured. (All catches made by "Dana").

Station	Date	Latitude	Longitude	Wire out in meters	Surface temperature in centigrade	*Euthynnus yaito*	*Euthynnus lineatus*	*Euthynnus alletteratus*	Species unknown	Tot
848.....	2- 6-20	18°00′N.	64°14′W.	Surf.	26.0	0	0	1	0	1
893.....	29- 7-20	33°07′N.	77°00′W.	100	26.5	0	0	4	0	4
893.....	–	–	–	150	–	0	0	5	0	5
952.....	12- 5-21	17°55′N.	64°48′W.	100	–	0	0	1	0	1
1172 (5) ...	14-11-21	7°22′N.	46°51′W.	50	28.4	0	0	1	0	1
1174 (2) ...	16-11-21	5°35′N.	51°08′W.	600	28.0	0	0	1	0	1
1174 (4) ...	–	–	–	100	–	0	0	2	0	2
1174 (5) ...	–	–	–	50	–	0	0	10	0	10
1175 (1) ...	17-11-21	5°06′N.	51°35′W.	200	–	0	0	1	0	1
1175 (2) ...	–	–	–	100	27.7	0	0	14	0	14
1175 (3) ...	–	–	–	50	–	0	0	2	0	2
1205 (1) ...	14- 1-22	6°49′N.	80°25′W.	Surf.	?	0	4 (1 juv.)	0	0	4
1205 (2) ...	–	–	–	600	?	0	1	0	0	1
1205 (4) ...	–	–	–	300	?	0	1	0	0	1
1205 (5) ...	–	–	–	100	?	0	13	0	0	13
1206 (2) ...	–	6°40′N.	80°47′W.	4000	?	0	4	0	0	4
1206 (3) ...	–	–	–	3500	?	0	1	0	0	1
1206 (4) ...	–	–	–	3000	?	0	1	0	0	1
1206 (5) ...	–	–	–	2500	?	0	2	0	0	2
1206 (10) ..	–	–	–	200	?	0	2	0	0	2
1206 (11) ..	–	–	–	100	?	0	58	0	0	58
1208 (2) ...	16- 1-22	6°48′N.	80°33′W.	600	?	0	1	0	0	1
1208 (3) ...	–	–	–	300	?	0	2	0	0	2
1208 (5) ...	–	–	–	3000	?	0	2	0	0	2
1208 (6) ...	–	–	–	2500	?	0	1	0	0	1
1208 (17) ..	–	–	–	1600	?	0	1	0	0	1
1211.....	18- 1-22	8°24′N.	79°23′W.	50	25.7	0	13	0	0	13
1212.....	19- 1-22	8°40′N.	–	35	?	0	25	0	0	25
1352 (2) ...	21- 5-22	35°42′N.	73°43′W.	200	25.6	0	0	0	3	3
1352 (3) ...	–	–	–	150	–	0	0	0	1	1
1352 (4) ...	–	–	–	100	–	0	0	0	2	2
1352 (5) ...	–	–	–	50	–	0	0	5(?)	0	5
3513 (1) ...	7- 7-28	34°25′N.	7°38′W.	150	(St. 3514 = 23.5)	0	0	0	11	11
3513 (7) ...	8- 7-28	–	–	300	–	0	0	0	1	1
3513 (9) ...	–	–	–	100	–	0	0	0	10	10
3515 (1) ...	11- 7-28	35°14′N.	6°51.5′W.	200	–	0	0	0	2	2
3515 (2) ...	–	–	–	150	–	0	0	0	8	8
3546 (1) ...	21- 8-28	13°11′N.	70°26′W.	300	27.5	0	0	2	0	2
3548 (7) ...	3- 9-28	7°06′N.	79°55′W.	100	27.9	0	2	0	0	2
3549 (3) ...	4- 9-28	7°16′N.	78°30′W.	100	28.0	0	1	0	0	1
3553 (1) ...	5- 9-28	7°55′N.	79°02′W.	100		0	1	0	0	1
3683 (7) ...	2- 4-29	4°03′N.	123°26′W.	600	28.6	1	0	0	0	1
3683 (10) ..	–	–	–	50	–	3	0	0	0	3
3688 (2) ...	8- 4-29	6°55 N.	114°02′E.	3500		15	0	0	0	15
3688 (3) ...	–	–	–	3000		23	0	0	0	23
3688 (4) ...	–	–	–	2000		25	0	0	0	25
3690 (2) ...	10- 4-29	8°02′N.	109°36.5′E.	600	28.0	1	0	0	0	1
3690 (3) ...	–	–	–	300	–	2	0	0	0	2
3690 (4) ...	–	–	–	100	–	42	0	0	0	42
3709 (2) ...	12- 5-29	12°15′N.	109°26′E.	50	28.9	1	0	0	0	1
3723 (4) ...	30- 5-29	20°30.5′N.	125°28′E.	100	24.7	2	0	0	0	2

Appendix **Table 1.** Record of *Euthynnus* captured. (All catches made by "Dana" (Cont'd).

Station	Date	Latitude	Longitude	Wire out in meters	Surface temperature in centrigrade	*Euthynnus yaito*	*Euthynnus lineatus*	*Euthynnus alletteratus*	Species unknown	Total
23 (5) ...	30- 5-29	20°30.5′N.	125°28′E.	50	24.7	2	0	0	0	2
31 (5) ...	16- 6-29	14°37′N.	119°52′E.	50	29.0	1	0	0	0	1
57 (5) ...	16- 7-29	0°41.5′S.	134°14.5′E.	350		1	0	0	0	1
57 (6) ...	–	–	–	250		3	0	0	0	3
57 (7) ...	–	–	–	150		2	0	0	0	2
59 (1) ...	–	0°40.5′S.	134°15′E.	400		7	0	0	0	7
59 (2) ...	–	–	–	300		3	0	0	0	3
59 (13) ..	–	–	–	500		10 (?)	0	0	0	10
59 (14) ..	–	–	–	400		4	0	0	0	4
59 (15) ..	–	–	–	300		4	0	0	0	4
61 (5) ...	19- 7-29	0°33′S.	134°00′E.	400		11	0	0	0	11
61 (6) ...	–	–	–	300		3	0	0	0	3
61 (8) ...	–	–	–	150		1 (?)	0	0	0	1
64 (2) ...	27- 7-29	1°01′S.	137°20′E.	400	28.2	2	0	0	0	2
64 (4) ...	–	–	–	300	–	3	0	0	0	3
68 (10) ..	24- 7-29	1°20′S.	138°42′E.	600		1	0	0	0	1
68 (17) ..	25- 7-29	–	–	300		1	0	0	0	1
00 (1) ...	18- 8-29	7°53′S.	116°18′E.	1000	27.4	1	0	0	0	1
00 (5) ...	–	–	–	50	–	2 (?)	0	0	0	2
04 (4) ...	30- 8-29	9°09′S.	114°47′E.	100	24.5	2	0	0	0	2
09 (3) ...	4- 9-29	6°22′S.	105°12′E.	100	27.7	7 (?)	0	0	0	7
09 (4) ...	–	–	–	50	–	13 (?)	0	0	0	13
14 (6) ...	9- 9-29	4°38′S.	99°24′E.	150		1	0	0	0	1
17 (4) ...	11- 9-29	2°00′S.	98°59′E.	100	29.0	1	0	0	0	1
17 (9) ...	–	–	–	200	–	1	0	0	0	1
17 (11) ..	–	–	–	100	–	2	0	0	0	2
18 (1) ...	12- 9-29	2°07′S.	99°53′E.	300		1	0	0	0	1
19 (1) ...	13- 9-29	1°29′S.	100°07′E.	300		2	0	0	0	2
19 (2) ...	–	–	–	200		10	0	0	0	10
21 (3) ...	14- 9-29	0°52′S.	99°25′E.	300	28.8	1	0	0	0	1
21 (4) ...	–	–	–	200	–	11	0	0	0	11
21 (5) ...	–	–	–	100	–	7	0	0	0	7
60 (1) ...	19-10-29	2°57′S.	99°36′E.	350	28.7	1	0	0	0	1
61 (3, 7)	21-10-29	3°12′S.	99°26′E.	200 & 250		1	0	0	0	1
04 (4) ...	11- 3-30	10°21′N.	17°59′W.	100		0	0	0	2	2
otal larvae						238	135	49	40	462
otal juveniles						0	1	0	0	1
otal larvae and juveniles						238	136	49	40	463

Appendix **Table 2.** Record of *Auxis* captured.

Station	Vessel	Date	Latitude	Longitude	Wire out in meters	Surface temperature in centrigrade	*Auxis* type I	*Auxis* type II	T
471	"Florida"	6- 4-12	20°44′N.	39°53′W.	15		0	1	
893	"Dana"	29- 7-20	30°07′N.	77°00′W.	100	26.5	2	6	
893	–	–	–	–	150	–	0	8	
901	–	22- 2-21	17°55′N.	64°48′W.	100	27.0	1	0	
1121	–	24- 9-21	36°38′N.	2°00′W.	25	24.3	1	0	
1122 (2)	–	25- 9-21	37°12′N.	1°08′E.	200	23.8	0	1	
1122 (4)	–	–	–	–	100	–	1	0	
1123 (3)	–	26- 9-21	37°48′N.	2°44′E.	100	24.5	2	1	
1123 (4)	–	–	–	–	50	–	1	1	
1123 (5)	–	–	–	–	25	–	0	6	
1125 (1)	–	30- 9-21	36°50′N.	2°58′E.	100		0	2	
1126 (5)	–	1-10-21	37°06′N.	2°25′E.	100	22.7	0	1	
1130 (3)	–	2-10-21	36°38′N.	2°00′W.	200	24.4	1	0	
1172 (2)	–	14-11-21	7°22′N.	46°51′W.	600	28.4	5	0	
1172 (3)	–	–	–	–	300	–	1	0	
1172 (4)	–	–	–	–	100	–	33	0	
1172 (5)	–	–	–	–	50	–	439	0	4
1173 (4)	–	15-11-21	6°18′N.	48°58′W.	100	27.5	1	0	
1203 (5)	–	11- 1-22	7°30′N.	79°19′W.	50	?	0	1	
1205 (1)	–	14- 1-22	6°49′N.	80°25′W.	Surf.	?	4	0	
1205 (4)	–	–	–	–	300	?	0	1	
1205 (5)	–	–	–	–	100	?	1	0	
1206 (2)	–	–	6°40′N.	80°47′W.	4000	?	0	2	
1206 (3)	–	–	–	–	3500	?	0	3	
1206 (4)	–	–	–	–	3000	?	0	3	
1206 (5)	–	–	–	–	2500	?	0	1	
1206 (6)	–	–	–	–	Surf.	?	2	0	
1206 (8)	–	–	–	–	800	?	2	0	
1206 (10)	–	–	–	–	200	?	0	3	
1206 (11)	–	–	–	–	100	?	0	14	
1208 (5)	–	16- 1-22	6°48′N.	80°33′W.	3000	?	0	1	
1208 (17)	–	–	–	–	1600	?	0	2	
1212	–	19- 1-22	8°40′N.	79°30′W.	35	?	0	1	
1214 (5)	–	26- 1-22	14°21′N.	76°50′W.	100	26.4	1	0	
1214 (6)	–	–	–	–	50	–	1	0	
1238 (4)	–	11- 2-22	26°13′N.	78°48′W.	100	23.6	3	0	
1261 (4)	–	9- 3-22	19°04′N.	65°43′W.	100	?	1	0	
1261 (5)	–	–	–	–	50	?	2	0	
1281 (10)	–	1- 4-22	17°43′N.	64°56′W.	50	24.9	1	0	
1283 (6)	–	5- 4-22	14°38′N.	61°16′W.	Surf.	26.1	3 (2 juv.)	0	
1284 (6)	–	6- 4-22	–	–	Surf.	26.0	1	0	
1285 (3)	–	7- 4-22	–	–	300	26.1	1	0	
1285 (6)	–	–	–	–	Surf.	–	2 (1 juv.)	0	
1289 (11)	–	15- 4-22	17°32′N.	64°56′W.	50	25.3	1	0	
1292 (6)	–	16- 4-22	17°43′N.	–	50	25.4	1	0	
1352 (2)	–	21- 5-22	35°42′N.	73°43′W.	200	25.6	2	4	
1352 (3)	–	–	–	–	150	25.6	1	5	
1352 (4)	–	–	–	–	100	–	3	11	
1352 (5)	–	–	–	–	50	–	0	6	
3513 (1)	–	8- 7-28	34°25′N.	7°38′W.	150	(St. 351=23.5	3	12	
3513 (3)	–	–	–	–	50	–	0	7	
3513 (7)	–	–	–	–	300	–	0	1	
3513 (8)	–	–	–	–	200	–	0	1	
3513 (9)	–	–	–	–	100	–	0	14	
3515 (1)	–	11- 7-28	35°14′N.	6°51.5′W.	200	–	0	1	
3515 (2)	–	–	–	–	150	–	0	3	
3515 (3)	–	–	–	–	100	–	0	10	
3546 (1)	–	21- 7-28	13°11′N.	70°26′W.	300	27.5	28	346	
3546 (2)	–	–	–	–	200	–	206	0	
3546 (3)	–	–	–	–	100	–	118	0	
3547 (2)	–	24- 8-28	11°00′N.	77°40′W.	200	27.6	2	0	
3547 (3)	–	–	–	–	100	–	3	0	
3548 (7)	–	3- 9-28	7°06′N.	79°55′W.	100	27.9	0	1	
3549 (3)	–	–	–	–	100	28.0	0	1	
3553 (1)	–	5- 9-28	7°55′N.	79°02′W.	100		1	2	
3553 (2)	–	–	–	–	50		2	3	
3553	–	–	–	–	Surf.		0	1	
3567 (1)	–	4-10-28	9°06′S.	140°21.5′W.	300		2	0	
3567 (2)	–	–	–	–	100		1	0	
3657 (1)	–	31- 5-29	33°17′S.	152°45′E.	1000	St. 3658=22.5	1	0	
3657 (5)	–	–	–	–	50	–	8	2	
3681 (3)	–	28- 3-29	0°29′N.	125°54′E.	300	28.5	1	0	

Appendix **Table 2.** Record of *Auxis* captured (Cont'd).

Station	Vessel	Date	Latitude	Longitude	Wire out in meters	Surface temperature in centigrade	*Auxis* type I	*Auxis* type II	Total
81 (5)	"Dana"	28- 3-29	0°29′N.	125°54′E.	50	28.5	1	0	1
83 (8)	"	2- 4-29	4°03′N.	123°26′E.	300	28.6	0	1	1
83 (10)	"	"	"	"	50	"	1	4	5
84 (4)	"	3- 4-29	6°37′N.	122°24′E.	100	28.7	1	0	1
87 (4)	"	8- 4-29	7°14′N.	115°23′E.	100	27.8	1	1	2
87 (5)	"	"	"	"	50	"	0	1	1
88 (2)	"	"	6°55′N.	114°02′E.	3500	"	0	4	4
88 (3)	"	"	"	"	3000	"	0	3	3
88 (4)	"	"	"	"	2000	"	2	0	2
88 (5)	"	"	"	"	1000	"	0	2	2
90 (2)	"	10- 4-29	8°02′N.	109°36.5′E.	600	28.0	9	2	11
90 (3)	"	"	"	"	300	"	3	5	8
90 (4)	"	"	"	"	100	"	69	55	124
90 (5)	"	"	"	"	50	"	27	0	27
09 (2)	"	12 -5-29	12°15′N.	109°26′E.	50	28.9	1	1	2
23 (2)	"	30 -5-29	20°30.5′N.	125°28′E.	600	24.7	1	0	1
23 (3)	"	"	"	"	300	"	1	0	1
23 (4)	"	"	"	"	100	"	1	0	1
23 (5)	"	"	"	"	50	"	27	0	27
28 (3)	"	12- 6-29	24°15′N.	122°00′E.	300	27.1	0	1	1
39 (2)	"	2- 7-29	3°20′N.	123°50′E.	600	28.3	0	2	2
39 (4)	"	"	"	"	100	"	3	17	20
39 (5)	"	"	"	"	50	"	3	8	11
55 (4)	"	15- 7-29	0°30.5′S.	134°13′E.	100	"	1	3	4
55 (5)	"	"	"	"	50	"	4	5	9
57 (5)	"	16- 7-29	0°41.5′S.	134°14.5′E.	350	"	38	21	59
57 (6)	"	"	"	"	250	"	11	6	17
57 (7)	"	"	"	"	150	"	4	1	5
57 (8)	"	"	"	"	100	"	1	3	4
59 (1)	"	"	0°40.5′S.	134°15′E.	400	"	28	8	36
59 (2)	"	"	"	"	300	"	4	8	12
59 (3)	"	"	"	"	200	"	0	1	1
59 (4)	"	"	"	"	150	"	1	0	1
59 (13)	"	"	"	"	500	"	31	13	44
59 (14)	"	"	"	"	400	"	14 (1 juv.)	9	23
59 (15)	"	"	"	"	300	"	4	8	12
59 (16)	"	"	"	"	200	"	1	3	4
61 (5)	"	19- 7-29	0°33′S.	134°00′E.	100	"	7	22	29
61 (6)	"	"	"	"	300	"	3	4	7
61 (7)	"	"	"	"	200	"	3	2	5
61 (8)	"	"	"	"	150	"	4	3	7
64 (2)	"	21- 7-29	1°01′S.	137°20′E.	400	28.2	2	0	2
64 (4)	"	"	"	"	300	"	3	4	7
66 (6)	"	22- 7-29	1°13′S.	138°43′E.	600	"	1	0	1
66 (15)	"	"	"	"	300	"	1	0	1
68 (7)	"	24- 7-29	1°20′S.	138°42′E.	600	"	1	0	1
68 (16)	"	"	"	"	400	"	3	1	4
68 (17)	"	25- 7-29	1°20′S.	138°42′E.	300	"	1	1	2
72 (1)	"	27- 7-29	0°37′S.	134°29′E.	500	"	0	2	2
72 (2)	"	"	"	"	400	"	1	1	2
72 (3)	"	"	"	"	300	"	1	1	2
72 (4)	"	"	"	"	100	"	0	1	1
75 (3)	"	29- 7-29	0°02′S.	131°18′E.	200	28.4	1	3	4
75 (4)	"	"	"	"	100	"	1	0	1
79 (3)	"	1- 8-29	0°28′S.	126°47′E.	150	"	3	0	3
00 (2)	"	18- 8-29	7°53′S.	116°18′E.	600	27.4	0	1	1
00 (3)	"	"	"	"	300	"	10	0	10
00 (4)	"	"	"	"	100	"	3	0	3
00 (5)	"	"	"	"	50	"	4	0	4
04 (2)	"	30- 8-29	9°09′S.	114°47′E.	600	24.5	2	1	3
04 (3)	"	"	"	"	300	"	6	2	8
04 (4)	"	"	"	"	100	"	70	16	86
17 (2)	"	11- 9-29	2°00′S.	98°59′E.	600	29.0	0	1	1
17 (4)	"	"	"	"	100	"	1	0	1
17 (5)	"	"	"	"	50	"	1	1	2
17 (6)	"	"	"	"	200	"	2	0	2
17 (7)	"	11- 9-29	2°00′S.	98°59′E.	150	29.0	2	0	2
17 (8)	"	"	"	"	100	"	1	0	1
17 (9)	"	"	"	"	200	"	2	0	2
17 (10)	"	"	"	"	150	"	2	0	2
17 (11)	"	"	"	"	100	"	10	0	10
19 (2)	"	13- 9-29	1°29′S.	100°07′E.	200	"	9	1	10

Appendix **Table 2.** Record of *Auxis* captured (Cont'd).

Station	Vessel	Date	Latitude	Longitude	Wire out in meters	Surface temperature in centigrade	*Auxis* type I	*Auxis* type II	To
3819 (3)	"Dana"	13- 9-29	1°29′S.	100°07′E.	100		4	1	
3821 (2)	–	14- 9-29	0°52′S.	99°25′E.	600	28.8	1	0	
3821 (4)	–	–	–	–	200	–	5	0	
3821 (5)	–	–	–	–	100	–	21	0	2
3822 (1)	–	–	–	–	200		7	0	
3822 (3)	–	–	1°00′S.	98°12′E.	100		4	0	
3830 (1)	–	19- 9-29	–	–	300	28.1	2	0	
3830 (4)	–	–	2°36′N.	96°31′E.	100	–	0	1	
3838 (1)	–	25- 9-29	1°47′S.	100°08′E.	300		3	0	
3860 (1)	–	19-10-29	2°57′S.	99°36′E.	350	28.7	4	1	
3860 (5)	–	–	–	–	400	28.7	1	0	
3860 (7)	–	–	–	–	300	–	1	0	
3860 (12, 17)	–	–	–	–	250	–	3	2	
3860 (8)	–	–	–	–	250	–	1	0	
3860 (9, 13)	–	–	–	–	400	–	2	0	
3860 (11, 15)	–	–	–	–	300	–	5	2	
3860 (20)	–	–	–	–	600	–	2	0	
3860 (22)	–	–	–	–	100	–	2	0	
3860 (23)	–	–	–	–	50	–	2	0	
3861 (3, 7)	–	21-10-29	3°12′S.	99°26′E.	200 & 250		2	0	
3903 (3)	–	17-11-29	5°50′N.	93°28′E.	300		3	0	
3903 (5)	–	–	–	–	50		2	1	
4002	–	7- 3-30	8°14′N.	13°37′W.	50		1	0	
4772	"Pacific"	12- 4-33	21°40′N.	120°02′E.	201	26.0	0	7	
4819	–	22- 6-37	12°01′N.	111°38′E.	201	31.0	0	1	
Total larvae							1,425	770	2,1
Total juveniles							4	0	
Total larvae and juveniles							1,429	770	2,1

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Effect of Water Clarity on Albacore Catches

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ABSTRACT

The numbers of albacore (*Germo alalunga*) taken by gill-netting and surface trolling are seriously affected by the transparency of the water. Observations assembled from a fishing cruise between Hawaii and the Aleutians in 1956 and from a cruise off the Pacific coast of North America in 1957 showed that the efficiency of the troll was greater in clear water than in more turbid water. Very likely this increase in efficiency is a power function of the change in transparency. Though the data are not so convincing, the results suggested that the gill net fishes more efficiently in turbid water. The ratio of troll catch to gill-net catch bears the following relation to a reciprocal function of the extinction coefficient—

$$\frac{\text{Troll} \times 100}{\text{Gill net}} = .0000394 \left(\frac{1.7}{\text{Extinction coefficient}} \right)^{4.55}$$

Since the theoretical maximum power function of the troll catches alone is about 3, the residual of 1.55 may be associated with the reverse effect that water clarity has on the efficiency of the gill net.

These data are discussed in relation to evaluating the abundance of any species of fish when the method of assessment involves visual responses. In addition, the possibility is discussed that water clarity may be an important ecological factor in the ocean in that the efficiency of sight feeders will be reduced as turbidity increases.

INTRODUCTION

Students of the ocean have long recognized that water clarity is an important ecological variable through its effect on photosynthesis (Clarke 1939) and on the maximum depth at which organisms might be able to see (Clarke 1936). Tamura (1957) and other investigators have concerned themselves with the morphology and histology of fish eyes and with measurements of the thresholds of vision in terms of illumination and of the most efficient level of illumination for vision (Tamura *et al.* 1957). Finally, in recent years there has been considerable attention devoted to variation in the optical properties of ocean water with depth (Jerlov 1951). Our concern is with a slightly different aspect of the problem. We wish to consider how far a fish can see in its normal habitat (a quantity similar to visual range as defined by Jenkins and Bowen 1946), and its effect on distribution and sampling of the fish.

In 1955 the writer hypothesized that the clarity of oceanic waters may have a direct influence on the abundance and distribution of tunas through its effect on their ability to forage. The hypothesis seemed to have merit, and observations and preliminary investigations pertinent to the problem were initiated shortly thereafter. A study of the morphology and histology of tuna eyes was begun under contract at the University of Hawaii, and we began measuring water clarity in connection with fishing surveys insofar as instrumentation and time permitted.

The material to be presented here does not permit direct discussion of the primary hypothesis. Rather, it shows that methods of catching tuna that depend on visual response of the fish are efficient in proportion to the clarity of the waters—by implication supporting the original hypothesis. The evidence shows that trolling, which depends on a positive visual response, is most efficient in clear water, whereas gill-netting, which is dependent on non-response, is most efficient in turbid water.

MATERIALS AND METHODS

The data utilized in this study were collected during the course of two albacore

(*Germo alalunga*) fishing surveys. The first survey was conducted in the summer of 1956 in temperate waters lying between Hawaii and the Aleutian Islands. The second survey was made during the summer of 1957 in the waters off the west coast of the United States. For the purposes of this study pertinent observations were grouped into synthetic stations. These are centered on overnight gill-net sets, and also include trolling during the afternoon preceding and the morning following the gill-net sets. Daylight extinction measurements were made near mid-day before and after the gill-net sets.

Daylight extinction was measured by determining the depth at which 5 per cent and 10 per cent of the surface illumination persisted. The apparatus consisted of a deck cell, mounted on gimbals and containing a Weston Photronic Model 856 type 1 photoelectric cell, and a similar submerged cell, each equipped with a suitable filter to match its response to the standard luminosity curve adopted by the International Commission on Illumination. A microammeter completed the apparatus. Determinations were made by placing an appropriate calibrated cover over the deck cell and lowering the sea cell until its current output equalled that of the deck cell. The two determinations (5 and 10 per cent) were coverted to extinction coefficients (Sverdrup *et al.* 1942, p. 82), and the two extinction coefficients were averaged. As might be expected from the differential extinction of different wave lengths of light through a water column and the possibility of heterogeneity of the water columns, the two coefficients (5 and 10 per cent) were not identical, but they generally bore a linear relation to one another and to the average of the two, suggesting that the average coefficient is a useful relative measure of transparency.

A final problem with respect to the extinction coefficients was to derive a value for each synthetic station that would be representative of clarity during trolling and gill-netting. Since ordinarily the ship moved 10–60 miles from one noon to the other, that is, from one light measurement to the next, there were no transparency observations directly associated with the gill-netting. Though somewhat unsatisfactory, our method of solving the difficulty was to average the two noon values of clarity bracketing the fishing, on the assumption that transparency varied linearly between stations. The light penetration measurements when plotted on surface charts to check this assumption indicated that, by and large, transparency varied in a progressive manner over a noon-to-noon vessel track. In three instances additional values obtained two or three days before or after a synthetic station were included because they fell on the vessel track. Thus each extinction coefficient employed here usually is the mean of four field determinations: two (5 and 10 per cent) at the noon preceding the fishing effort; and two (5 and 10 per cent) at the noon immediately following the fishing effort. It should be noted that the most turbid water encountered corresponded roughly to the oceanic maximum recognized by Sverdrup *et al.* (1942, p. 85) and that none would fall in the category of coastal water with respect to turbidity.

Trolling was generally carried out with the vessel proceeding at 5–7 knots, trailing 5 or 6 lines. These lines bore a variety of "albacore lures," and there was no indication from the catch that one lure was superior to the others. No adjustments were made in the raw troll catches except for one station during which there was no trolling on the morning following the gill-net station. In that instance the troll catch of the afternoon preceding the gill-net station was arbitrarily doubled.

The albacore gill nets were made up of shackles about 300 feet long and 30 feet deep, with mesh size ranging from 4½ to 7½ inches (stretched measure). Between 9 and 18 shackles were fished at each station, 12 being the typical number. Since all mesh sizes took albacore, we have made no attempt to adjust the catch for varying proportions of the different mesh sizes. Rather, the results are expressed in terms of catch per 12 shackles of net. Gill nets were set at dusk and hauled just prior to dawn.

Approximately 35 sets of fish-catch and transparency measurements were available

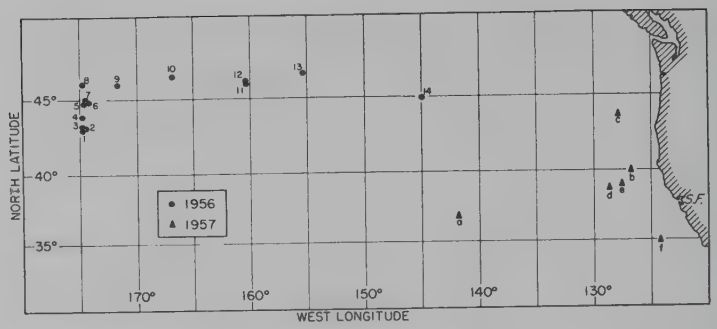

FIG. 1. Northeastern Pacific Ocean, showing the locations of troll and gill-net stations used in this study. The July-August 1956 cruise is represented by solid circles and the June-August 1957 cruise by triangles.

TABLE 1. *Albacore catches and mean extinction coefficients during 1956 and 1957*

Dates and positions refer to the start of the gill-net stations. Gill-net catches are adjusted to 12 shackles. Troll catches are from noon to noon bracketing the gill-net stations. Extinction coefficients are the means of the 10 and 5 per cent determinations of all light stations during the noon-to-noon periods.

Station	Date	Latitude	Longitude	Gill-net catch	Troll catch	Extinction coefficient
1	7–25–56	43° 02′ N	174° 57′ W	27	5	.119
2	7–26–56	43° 07′ N	174° 52′ W	81	1	.137
3	7–27–56	43° 10′ N	174° 53′ W	33	1	.148
4	7–28–56	43° 56′ N	174° 57′ W	16	1	.157
5	7–31–56	44° 48′ N	174° 46′ W	112	11	.086
6	8–1–56	44° 54′ N	174° 08′ W	32	11	.090
7	8–2–56	44° 58′ N	174° 29′ W	33	6	.094
8	8–3–56	46° 01′ N	174° 58′ W	16	0	.089
9	8–16–56	45° 57′ N	171° 44′ W	53	4	.095
10	8–19–56	46° 28′ N	166° 54′ W	33	3	.130
11	8–21–56	46° 00′ N	160° 16′ W	63	0	.130
12	8–22–56	46° 03′ N	160° 16′ W	79	0	.149
13	8–26–56	46° 25′ N	155° 15′ W	13	0	.116
14	9–1–56	44° 57′ N	145° 01′ W	4	7	.106
a	6–19–57	36° 53′ N	141° 41′ W	27	4	.052
b	7–9–57	39° 59′ N	126° 51′ W	3	12	.063
c	7–23–57	43° 42′ N	127° 53′ W	11	12	.072
d	7–28–57	38° 45′ N	128° 37′ W	2	15	.055
e	7–29–57	39° 00′ N	127° 31′ W	28	6	.074
f	8–9–57	34° 50′ N	124° 10′ W	2	13	.071

for study. These were reduced to 20 by considering only those stations in which the aggregate catch of the gill-net set and the trolling was 10 or more fish. This limitation reduced the variability in the data and, perhaps even more important, restricted the study to waters in which albacore were present in fair numbers. Thus, the problem of the general distribution of albacore and the possible interaction of other environmental factors on the catches, such as temperature, is minimized. The locations of the 20 stations that met the above criterion are shown in Figure 1 and the data are tabulated in Table 1.

RESULTS

The results of gill-netting show little numerical relation to the troll catches (Fig. 2). Though far below the level of statistical significance, the two have a negative correlation coefficient as would be expected if they are affected in opposite ways by water clarity. Statistically significant results should not be expected, however, without enormous amounts of data, because the treatment does not overcome variations in the absolute abundance of albacore from station to station; and since two measures of abundance are plotted, this effect is doubled.

Troll catches, plotted as a function of water clarity (extinction coefficient), show a negative relation ($r = -0.738$, $P < 0.01$) (Fig. 3). A linear function was applied, not because it is proposed that the two variables bear a linear relation to each other, but rather as a simple way to show that there is an association between them. Again, an unknown source of variability in this treatment must be the changes in the true abundance of albacore from station to station. However, the effect of this source of variability is less than in the previous analy-

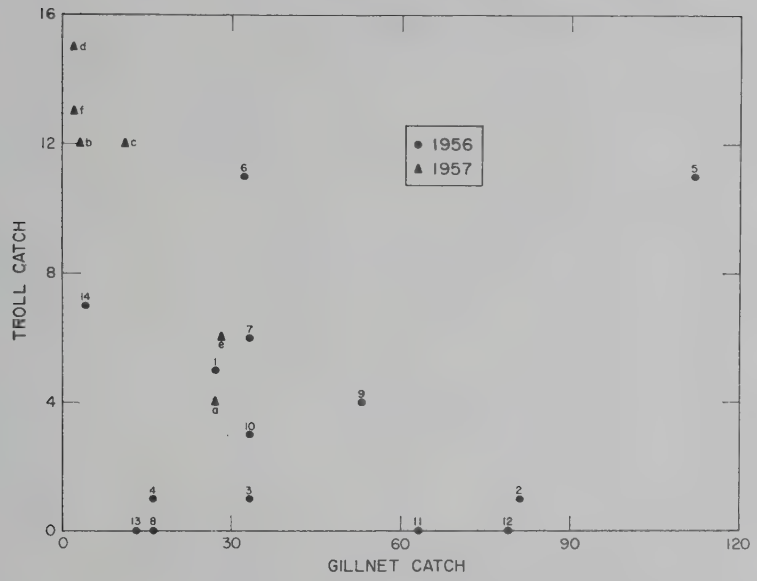

FIG. 2. Troll catch of albacore, plotted against the gill-net catch.

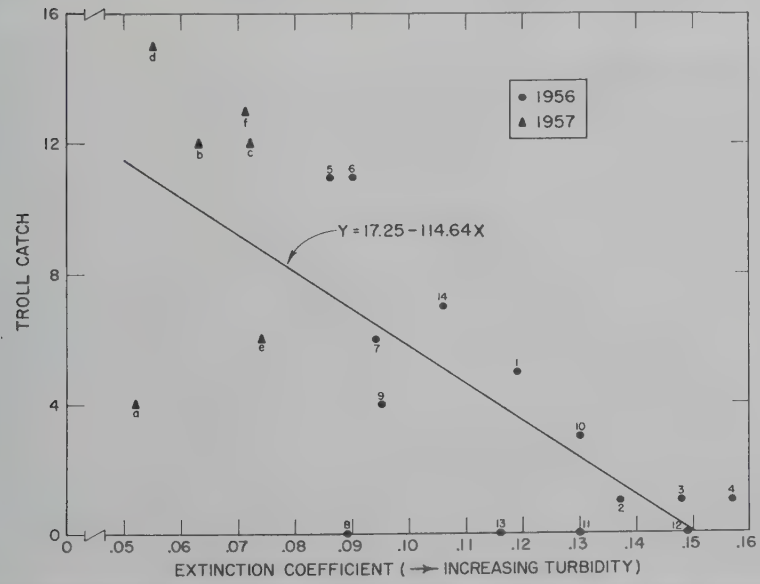

FIG. 3. Albacore troll catches plotted against water transparency. The larger extinction coefficients represent less transparent water.

sis because we consider only one measurement of the albacore population. Figure 3 could, of course, be interpreted to mean that albacore are most abundant in clear water or that trolling is most effective in clear water or, as a third possibility, there may be an interaction or systematic effect of the different variables.

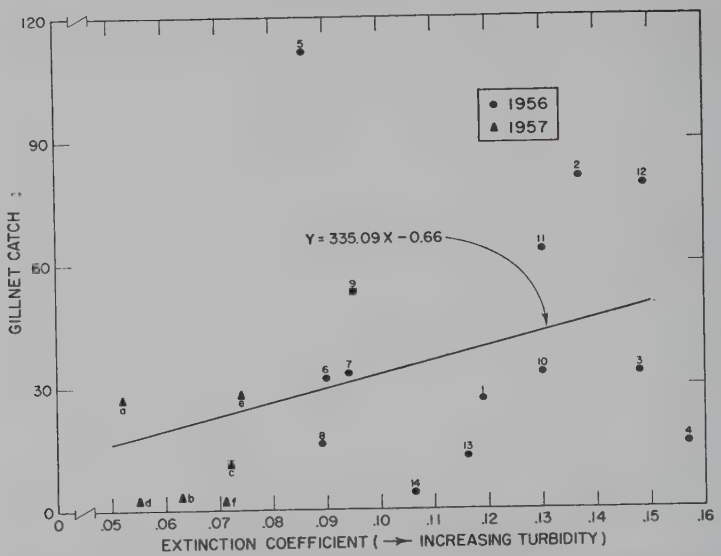

FIG. 4. Albacore gill-net catches plotted against water transparency. The larger extinction coefficients represent less transparent water.

Gill-net catches plotted against turbidity show a positive relation ($r = 0.36$, $P > 0.05$) (Fig. 4). Lack of statistical significance may well stem from the ever-present variability associated with differences in the actual density of the albacore population and the tendency for night gill-netting to reduce or perhaps even eliminate the effect of variations in water clarity. Auxiliary sources of light must also be considered with respect to the gill net. Extremely clear water is generally low in biomass and probably would produce little bioluminescence in the vicinity of the drifting gill net. Turbid water in the marine environment is generally high in biomass and might therefore result in high bioluminescence. This additional variable would operate to reduce the slope of the regression.

If we accept the slope in Figure 4, we are again offered three alternate conclusions: (1) that albacore are more abundant in more turbid water, (2) that the gill net fishes more efficiently in more turbid water, or (3) that there is systematic interaction among the variables. These are opposite to the conclusions drawn from the troll catches. If the slope, which falls slightly short of significance, is rejected in compliance with the usual statistical standards, we can conclude that the magnitude of the gill-net catch and presumably the density of the albacore population is independent of water clarity.

The preceding analyses of water clarity and albacore catches were handicapped by inability to estimate or control variations in absolute abundance from station to station. One way to eliminate the effect of absolute abundance is to express the catches as a ratio (Troll catch ÷ Gill-net catch), adding "1" to the three zero catches in Table 1. If these ratios are plotted against water clarity, the slope obtained will be independent of abundance and should only reflect the relative efficiency of the two sampling methods with respect to water clarity. This treatment has the disadvantage of introducing into one analysis all sources of random variability, that is, variability in gill-net catches, troll catches, and random errors in assessing water clarity.

In this final analysis an approximation of

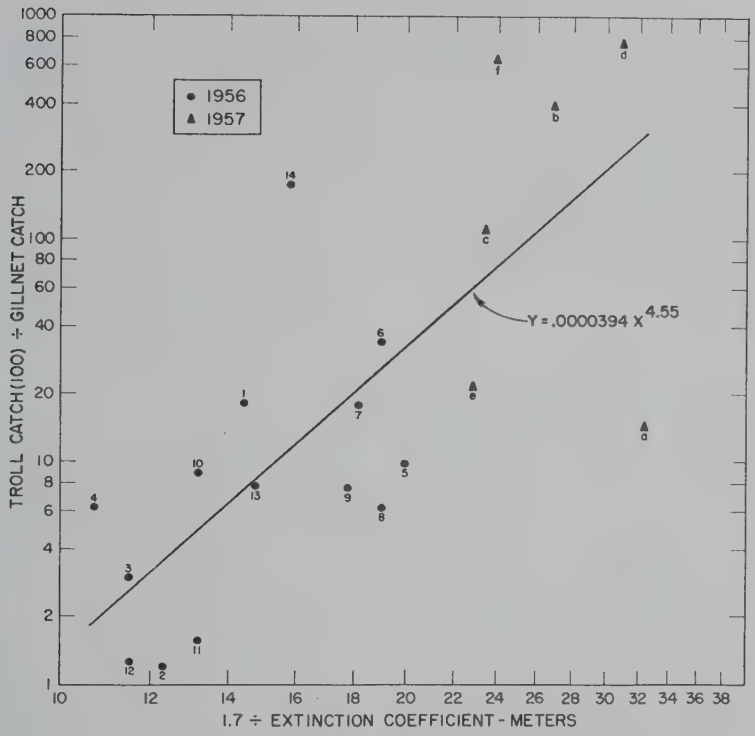

FIG. 5. The ratio of troll to gill-net catches plotted as a function of the reciprocal of the extinction coefficient.

the distance an albacore can see (visual range), *i.e.*, $\frac{1.7}{K}$ is employed as the measure of water clarity instead of the extinction coefficient (K). This reciprocal quantity of the extinction coefficient was found by Poole and Atkins (1929) to be equal to the vertical depth at which a Secchi disk could be seen in the English Channel. A comparison of our Secchi disk measurements and the computed $\frac{1.7}{K}$ indicates the latter is also a good approximation in these waters. (The observed Secchi disk measurements were not used in the present study because they lack the precision of the photoelectric determinations, principally because of variation in boundary conditions at the sea surface.)

The relative efficiency of the two sampling methods $\left(\frac{\text{Troll} \times 100}{\text{Gill net}}\right)$ is treated as a power function of the visual range $\left(\frac{1.7}{K}\right)$ because the efficiency of the troll should be related to some power of the radius of vision, that is, the visual range. Thus the following type of equation should obtain—

$$\frac{\text{Troll} \times 100}{\text{Gill net}} = a\left(\frac{1.7}{K}\right)^b$$

The empirical solution to the above equation (Fig. 5) gives a value of 3.95×10^{-5} for a and 4.55 for b. The slope is highly significant ($P < 0.001$) as is the associated correlation ($r = 0.772$). Again, as suggested by the other treatments, the efficiency of the troll in respect to the gill net is apparently a function of water clarity. This analysis tends to implicate the gill net as well as the troll, because the b value (4.55) is higher than might be expected if the gill net is unbiased with respect to water clarity. That is, if an instantaneous function is con-

sidered, the volume of water in which the troll lure is visible to albacore should be close to a cube function of the visual range because an object near the surface is visible to all fish in a "hemisphere," with locus at the object and a radius equal to the visual range.[1] No significantly higher exponent can be theorized, so most of the residual (1.55) must be either related to increasing gill-net efficiency with increasing turbidity or to sampling error or both.

DISCUSSION

The validity of using extinction coefficients (K) to estimate how far a fish can see is not clearly established. Poole and Atkins (1929) showed that in the English Channel $\frac{1.7}{K}$ was a linear function of the vertical limit of Secchi disk visibility. The present problem, however, involves vision at all angles from the horizontal to the vertical. We have made measurements comparing vertical and horizontal Secchi disk visibility at two locations in Hawaiian waters with the observer on a submerged platform about 4 feet below the sea surface. In each of two pairs of observations, one determination was made vertically and a second, with a similar target, horizontally, the target being suspended from a buoy about 10 feet below the surface. In each instance the vertical and horizontal determinations were nearly identical, varying about 10 feet (vertical distances 150 and 180 feet). Thus the vertical Secchi disk determinations appear to provide a fairly close approximation of horizontal visual range. Since this quantity is a function of the extinction coefficient it appears that the use of $\frac{1.7}{K}$ as a first approximation of visual range is justified. The basic reason for the validity of this approximation lies in fact that loss of contrast through scattering is the most important element in fixing "visual range" in the open ocean, with absolute level of initial illumination of minor importance (Duntley 1952).

Perhaps it is redundant to point out that the evidence given questions the validity of estimates of tuna abundance if the methods are such that the fish can employ vision in a positive or negative sense in relation to the gear. A case in point are Figures 3, 4, and 5 in which the data for 1957, while not incompatible with those obtained in 1956, are not randomly distributed with respect to the 1956 results. This apparently resulted because gill-net stations in 1957 were deliberately located in areas where trolling was "good," practically precluding a random distribution of gill-net catches with respect to water clarity. Comprehensive sampling programs employing two or more types of gear might help to overcome this problem, and more precise information on the magnitude of the effect of water clarity and other environmental factors on the efficiency of the sampling method might permit adjustment of catches to obtain a more reliable measure of actual abundance. Another alternative is to sample by means of measures not dependent on any reaction of the fish to visual stimuli. For instance, the gill net as used for albacore appears to be an improvement over the troll, though the gill net might be more susceptible to other factors such as the vertical distribution of fish and the thermal structure of the water. An ecologist attempting to relate abundance of, say, albacore to other factors in the environment might even better be served by the uncertain but unbiased estimates of fish abundance that might be obtained by echo sounders.

Though it is not possible to treat the subject with any precision, it is worthwhile to consider further the possible effect of water clarity on the absolute abundance of albacore and other sight feeders. The first problem, of course, is to establish that they are sight feeders. This is indicated with respect to

[1] The cube function is only an approximation because an object can be seen over the greatest range from directly below, and at a lesser distance from a horizontal direction (Duntley 1952). Thus the volume of water in which the lure is visible is an ellipsoidal solid with a vertical axis slightly greater than the horizontal. The present data do not permit precise resolution of the parameters involved, but trial computations show that no more than 0.2 of the 1.55 can be ascribed to deviations from a sphere.

albacore and other tunas by general observations on their behavior at sea and by such objective data as failure to make captures at night by trolling. It is also suggested by their large and presumably efficient eyes and by their ability to swim rapidly. Vision in the open ocean appears to be related to turbidity, which is of course related to the amount of particulate matter in the water. In the open ocean the amount of particulate matter is at least in part a function of the biomass; thus as the standing crop of food increases, the relative ability of the tunas to locate and capture a prey animal must decrease. Fish such as tuna might then be at a loss in an environment judged ideal on the basis of the standing crop of organisms. An extreme case of this effect might run as follows: A particular area contains a crop of tuna forage sufficient to support a particular density of tuna. An increase in the rate of replenishment of nutrients in that area through upwelling or some other phenomenon causes an upsurge of phytoplankton, thus decreasing the visibility. However, there might not yet be an increase in the tuna food supply so the tunas would be forced temporarily to desert this particular area. Perhaps this effect contributes to the reported exclusion of herring from dense populations of phytoplankton, for they also appear to employ vision in capturing food (Vilter 1950).

REFERENCES

Clarke, G. L. 1936. On the depth at which fish can see. Ecology, **17**(3): 452–456.

———. 1939. Variation in the transparency of three areas of the Atlantic throughout the year. Ecology, **20**(4): 529–543.

Duntley, S. Q. 1952. The visibility of submerged objects. Visibility Laboratory, Mass. Inst. of Tech., pp. 1–74. Aug. 31, 1952.

Jenkins, F. A., and I. S. Bowen. 1946. Transparency of ocean water. J. Optical Soc. Am., **36**(11): 617–623.

Jerlov, N. G. 1951. Optical studies of ocean waters. Repts. Swedish Deep-Sea Exped., 1947–48, **3**(1): 1–69.

Poole, H. H., and W. R. G. Atkins. 1929. Photo-electric measurements of submarine illumination throughout the year. J. Mar. Biol. Assoc. U. K., **16**(1): 297–324.

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The oceans. New York, Prentice-Hall, Inc. 1087 pp.

Tamura, T. 1957. A study of visual perception in fish, especially on resolving power and accommodation. Bull. Jap. Soc. Sci. Fish., **22**(9): 536–557.

Tamura, T., G. Mitarai, and Y. Sugita. 1957. The lowest intensity of illumination to produce the maximum cone potential in the fish retina and its ecological meaning. Bull. Jap. Soc. Sci. Fish., **23**(2): 86–91.

Vilter, V. 1950. Adaptation biologique de l'appariel visuel et les structures retiniennes de la sardine. J. Soc. Biol., **144**(3–4): 200–203.

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OBSERVATIONS ON AGGRESSIVENESS IN OCKEYE SALMON SMOLTS.—Juvenile sock-e salmon are usually strongly schooling fish Hoar, 1954, Jour. Fish. Res. Bd. Canada, *11*(1): 2). However, during laboratory observations on ie behavior of juvenile salmon, aggressiveness sockeye smolts was noted on several occasions. Hoar observed this too (*op. cit.*), stating that ipping by sockeye smolts does not have the cious appearance of coho nipping and never icits a retaliation.

In the Fish Behavior Laboratory, United States ish and Wildlife Service, Seattle, Washington, e conducted tests which confirm this observa-on and suggest that this behavior is defense of erritory.

Three individuals were removed from a group f schooling sockeye smolts and placed in a hree-chambered tank. They were allowed to ad-ust over night, then a fourth individual was ntroduced. There was no immediate response, ut soon one of the "resident" fish cautiously pproached the newcomer, then swam away. This ook place several times until the newcomer urned away. The resident fish renewed his mo-ions which then began to have a menacing air. Usually the newcomer took flight and chase was iven by the aggressor. The chase was of short uration and seldom, if ever, seemed to involve ny bodily contact. On one occasion, however, vith some very silvery smolts, there was biting or nipping and numerous scales were observed floating in the water.

The unwelcome stranger was usually displaced over a sill into another chamber where the process was repeated. The initial resident was not always successful; at times the intruder also made menacing moves and in some instances drove out the resident.

Fish which have been engaged in this chasing activity, when transferred to a larger, undivided tank containing several other fish, again schooled. Therefore, spatial relationships, container size, and numbers of fish appear to influence this behavior.

Having repeated this with young sockeye which had varying lengths of time in "residence" in the experimental tank, we believe that the aggressiveness is reinforced with more time in the chamber. Fish that were in the chambered tank for three days actually made bodily contact and produced abrasion, while other groups that were acclimatized either over night or for a few hours prior to adding the extra fish usually just chased the intruder.

Behavior of this type is of more than passing interest and must be taken into account when designing experiments which utilize small sized samples of fish. A sequence of this behavior has been filmed for future reference and study.—H. William Newman, *United States Fish and Wildlife Service, Bureau of Commercial Fisheries, Seattle, Washington.*

airplane hangar at Sebring, Florida, with
,000 square feet of working space, became
the laboratory.

BULLETS

re used in the

ght against wildlife pests

rvae, bury themselves in the wounds to feed on the
ing tissues.

In this screwworm eradication program, the scien-
ts have delved into nature's secrets to use her weak-
sses to destroy a pest. They found that atoms can se
er the screwworm fly that it will destroy itself while
ntinuing its normal habits of life and reproduction.
, we are using flies to destroy flies. The program
being carried out by the U. S. Department of Agri-
lture, Animal Disease Eradication Division, with
e Florida Livestock Board and other Southeastern
ate agencies.

The technique is based on simple principles but it
ok the scientists 20 years to mold them into the effec-
ve method used in the program. Here is how it works.

First, bear in mind that it is advantageous but not
sential to the program that the female screwworm
mates only once, the male up to 14 times. (Entomo-
gists worked years determining this as a certainty).
econd, a method has been developed to bring about
is one-time mating of the female fly without produc-
g fertile eggs. Chemicals were not effective, so ento-
ologists borrowed some research results from the
neticists and cytologists who were X-raying fruit
es to study radiation effects on heredity. Here they
und the answer — X-rays would make screwworm
es sterile without changing their vigor or habits.
ey found that a female screwworm fly mated to a
ale, exposed to X-rays, produced only infertile eggs.
ere remained only the problem of producing enough
erile flies to overwhelm the native populations.

But there was a fly in the ointment. X-rays cost too
uch to use for sterilizing flies in quantities necessary
for an eradication program. It took atomic energy research to supply the final link. Radioactive cobalt provided a relatively inexpensive and readily available source of gamma rays — atomic bullets — which produced the same effect as X-rays on screwworm flies. With a more adaptable and less hazardous source of irradiation available, plans were laid for eradication of the fly in areas that could be isolated by one means or another, or those in natural isolation.

To perfect the techniques, sterile flies were released on Sanibel and Captiva islands off the coast of Florida in 1951-53. Of course these islands were reinfested from the mainland, but the tests were so successful that sterile flies were released for 6 months on the screwworm-infested island of Curacao off Venezuela, in 1954. So far no screwworms cases have been reported from Curacao, four years later. This meant that infestations in wild animals were wiped out, too. But still the scientists were not satisfied. They selected a 2000-

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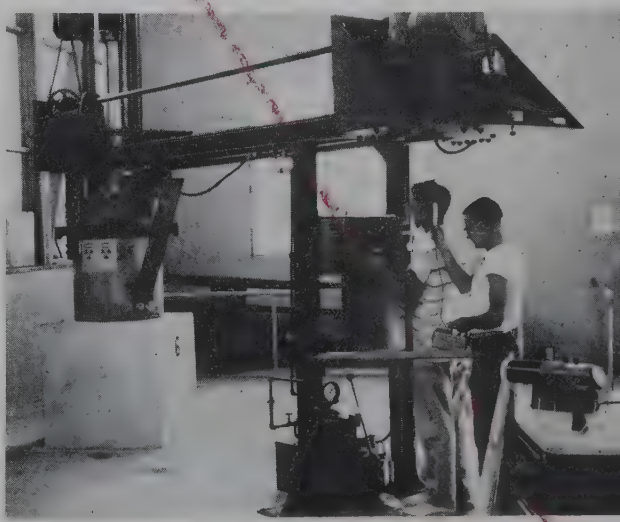
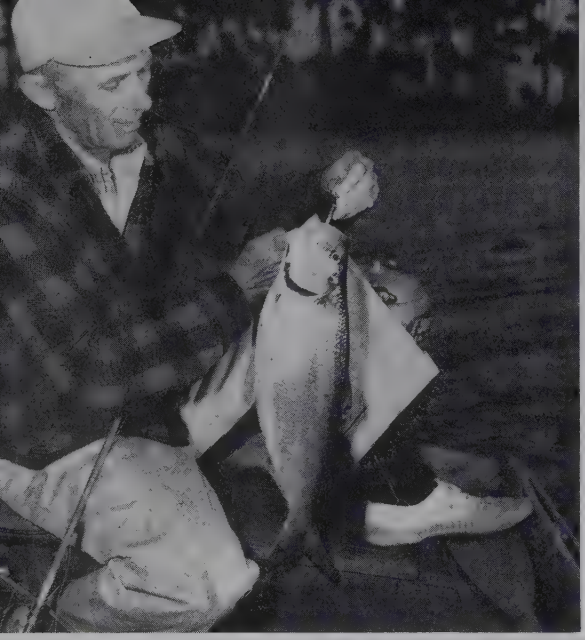


e of six radioactive cobalt units used to sterilize the pupae of screwworm flies.



Shad fishing on the St. Johns River usually starts early in December and continues until late April. During the 1957-58 season, an estimated 65,246 of the battling "silver demons" were boated, and kept.

ST. JOHNS SHAD FEVER

By PAUL R. NICHOLS
U. S. Fish and Wildlife Service

MANY A ST. JOHNS RIVER shad has felt the sting of a Cather spoon since Norton Webster, "the daddy of Florida shad fishing," accidentally hooked his first "bolt of greased lightning" in the spring of 1942 — in reality identified as a six and a half pounder. Disregarding how or why the first shad was attracted to Webster's fishing gear, the fact is that sport fishing for this silver demon is rapidly developing into one of Florida's most exciting pastimes.

This amusement is at the expense of the American shad, *Alosa sapidissima,* the largest and one of the more valuable members of the herring family of fishes in the United States. The name *Alosa* is Latin for "shad," and *sapidissima* means "good to eat." It occurs more or less abundantly along the entire Atlantic coast from the Gulf of St. Lawrence in Canada, to the St. Johns River in Florida, ascending the rivers to spawn where they are caught by all forms of apparatus from seines and nets near the coast to sport tackle in the upriver areas.

Because of the shad's wide geographic distribution, it is subject to a sizable variety of nicknames. It is commonly called just plain "shad" by Florida anglers, but northward it takes on different appelations such as "white shad," "poplar-back shad," "jacks," and in the Connecticut River, the "poor man's salmon."

Since 1953 the U. S. Fish and Wildlife Service, at the request of the Atlantic States Marine Fisheries Commission, has been investigating the St. Johns River shad. As a part of this investigation, studies were made on the sport fishery to determine fishing pressure and magnitude of the catch, and to obtain pertinent history information.

This sport fishing survey was made possible the help and cooperation of fish camp operators the many loyal shad fishermen who filled out cards dropped them in the white card boxes erected at different fish camp landings and public boat launc ramps. Local sportsmen's organizations and publ mediums co-operated in every way possible to in success of the creel census survey.

During the course of this study many quest were asked by shad anglers and interested bystan This article is an attempt to answer some of t inquiries.

Many people have watched shad on their spaw grounds or in "shad wallows," as they are terme the fishermen, but little is known about actual c ship and mating. With fresh water trout, as with m species, there is an unmistakable pairing, a prepara of the bottom for the eggs, an accompanying def of the breeding grounds, and a collaborative sex Among many aquarium fishes there are elabo "love-lives" in which both male and female tak active part. But when the shad males and fem reach the spawning grounds in schools and, wit any apparent nest building or prolonged court release their reproductive cells into the open w The eggs and young produced are then left to Mo Nature's care.

The first shad reach the major spawning gro of the St. Johns (Lake Monroe near Sanford upst to Lake Harney, a distance of approximately 25 m in late November or early December, and the run ally continues until late April or early May. The of the spawning season is from mid-March until April. Since the shad are open water spawners, na provided the parent with many chances for offspri the lesser the parental care, the larger the nu

Midwinter angling along the St. Johns River produces "dynamite in small packages"

eggs produced. The annual fecundity of the St. Johns ver female shad ranges from 290,000 to 660,000 eggs, pending on the length, weight, and age of the fish. though many young shad may be produced, the tween generation mortality is tremendous.

The eggs hatch in three to fourteen days, depend- g on water temperature. The young shad remain the river until fall when they make the long journey sea. While in the ocean, the shad make many cursions and travel many miles, as far as the coast Maine, searching for food.

After three to six years of ocean life the shad reach aturity, and its most important function becomes that reproduction. Instinctively they move to the coast, arching out the stream of their birth and moving ainst the river's current seeking their natural spawn- g grounds.

It is during this spawning migration and their stay the spawning area that the shad are available to e fishermen. Shad take little or no food during this ase of their life. Since adult shad are true plankton eders, they are not equipped to eat and utilize the od available in fresh water any more than an arma- lla is equipped to catch mice. When shad attack res, it is more likely a matter of defense of their awning grounds rather than offensive for food, as the case when a "schooling largemouth" strikes a arm's trailer minnow.

In the St. Johns, the shad usually have a long urney and extended sojourn. Last season fishing n for 23 weeks; from November 25, 1957 through ay 5, 1958, and during this period an estimated 65,246 ad were boated and kept. Of this total, 30,864 were ales (bucks) and 34,382 were females (roe). Respon- ble for the catch were 13,025 fishermen fishing from 002 boats for an average of 10.9 shad per boat. The eel limit for shad in Florida is 15 per person per day.

Shad in the St. Johns usually keep banker's hours, ith the peak of daily catches occurring from 10:00 m. to 5:00 p.m., gradually tapering off until dark, d low between 8:00 a.m. and 10:00 a.m. Regardless of the hours fished, the factor which seemed to influence the success of the angler was water temperature. The better catches were made when the water temperature was about 63 degrees and above. In addition to temperature, catch was also affected by number of fish available in certain areas and competition or skill differences between individual fishermen. Shad show no preference in personalities, but the three cardinal principles of fishing success—where, when, and how—cannot be overlooked.

The peak of the season was reached during the period February 24-March 2, when 1,285 fishermen boated 10,340 shad, with 189 boat parties recording 2,237 released. Thus, the reported grand catch was 67,483 shad, and that represents about 175,000 pounds, or 88 tons, which would fill a lot of home freezers with this piscatorial delicacy.

The average length by sex of the shad taken by the sport fishery last season was 15.2 inches fork length for male shad and 16.8 inches fork length for the female. The average weight of the shad taken was 2.1 pounds for male and 3.2 pounds for the female. The largest fish observed in last season's catch was a 5 pound, 2 ounce female.

The age distribution by sex showed that the majority of male shad were 3 and 4 years old, while the females were 4 and 5 years of age. The shad are aged

(Continued on Page 39)

e fight of the American shad is furious and continuous, right into landing net and boat. Since shad take little or no food during spawning season, their attack on a lure is probably of a defensive nature.

Two mocking birds attacked the huge hawk with utter ferocity.

Wildlife From My Window

My brand new home serves as an exciting wildlife observation post

By CLEVELAND VAN DRESSER

TWENTY-FIVE YEARS ago Hypoluxo Island, which lies in Lake Worth, eight miles south of glittering Palm Beach, Florida, was an almost forgotten strip of land three miles long and a half-mile wide at its extreme width. Except for a luxurious estate on the southernmost tip, the south end of the island was a tangle of dense jungle, cabbage and coconut palms, gumbo-limbo trees and the vestige of what at one time had been a large citrus grove. A rutty road wound its erratic way down to the estate. Here and there was a "squatter's" cottage. Outside of that, the south end of the island was pretty much in the state it was when the Barefoot Mailman trod the beaches from Palm Beach to Miami. Indeed, legend has it that the immortal mailman brought his bride to spend their honeymoon amid the untouched jungles of Hypoluxo Island.

The legend may or may not be true, but during World War Two, the military conducted survival tests on the island. Troops were dumped on Hypoluxo Island and told to "live off the land." That they managed to do so is sufficient testimony that Hypoluxo Island teemed with wildlife, and a multitude of fishes were to be caught off its shores.

During the past five years the Island has experienced a building boom of sorts (as has the entire surrounding east coast of Florida). A paved road now extends the full length of Hypoluxo, blossoming into an abbreviated "O" at its widest part. Two bridges connect the island with the mainland and the narrow strip of land that runs between Lake Worth and the Atlantic Ocean. Numerous dwellings have been erected on what was not long ago a virtual wilderness.

In short, Hypoluxo Island has been "discovered" by people whose taste runs to seclusion and privacy.

I built my home on the southern part of the Island and moved in during December of 1955. In clear the land, I left all the trees standing, and in fact b my patio around an immense tree which has four s arate trunks. At first there were no neighbors in si But "progress" is taking its toll. In the 2½ ye my wife and I have been on the Island, six dwelli have been erected within sight of our house. Oth have gone up or are in the process of being erec elsewhere on the southern portion of what has becc to us a beloved isle.

How has wildlife managed in the path of this exp sion?

We have learned, through first hand observat that wildlife is a tenacious thing — it does not g up easily. If one has patience and the ability to quietly, many strange and wonderful events take pl in the lives of the wild creatures on Hypoluxo Isla Between us, my wife and I have witnessed miniat wars, great loves, the age old story of the hunter the hunted—in short, the struggle for survival that gone on among Nature's creations since the beginn of time.

One afternoon in the spring of 1956 I was snooz in my bedroom in the southwest wing of the ho Suddenly there was a great commotion outside south window. I cautiously peered through the winc and beheld, not ten feet away, a huge hawk perc on the dead limb of a tree. Two mockingbirds w attacking it with utter ferocity.

The mockingbird, at times, gives forth the m dulcet notes in the realm of bird song. However, th two mockingbirds were anything but dulcet. They w fighting mad, and were going after the hawk lik pair of supersonic dive bombers. They took turns d ing down on the hawk at what appeared to be trem

SHAD FEVER

(Continued from Page 23)

rowth rings found on the scales, ar to rings that tell the age of a Still further, when the shad eparing to spawn, it gives up g and ceases to grow. During period the scale is slightly re- d, and when growth is resumed their return to the ocean, it s an unmistakable "spawning- " on the scale that stands out a black eye.

scale samples taken from shad led in the St. Johns showed any ation of having spawned the ious year since both male and le shad in the St. Johns River fter they have spawned. This be observed in the latter part pril or early May each year large white pelicans make annual appearance on the fish- grounds to feed on dead and g shad. Whether this catas- e is heritable, as is the case the Pacific salmon, or due to ronmental influences, is not fully vn. Adult shad in northern rs do not normally die after ning, and if they survive nat- and fishing mortality, they re- to spawn in successive years.

e question that most often arises ow to tell the difference be- n a male (buck) and a female) shad." Usually the female shad larger, but this is not always As the female "ripens" (ma- g of eggs) the area around the vent gets red in color and slight- rotrudes; whereas the male shad usually ripe at this time and the around the vent is white with little or no protruding. To ure, gently massage the belly rds the vent with thumb and inger. If a white substance ed milt) is extruded, it is sure e a male; and if a red grainy tance is extruded, then it is a le and you are in for a shad gg omelet for breakfast.

nce 1953, when the U. S. Fish Wildlife Service began their on the St. Johns River shad, nnual sport catch has increased from 31,860 to 65,246 in 1958, which makes this the most extensive sport fishery for shad along the Atlantic coast. This increase in sport catch has largely been due to an increase in fishing pressure — 3,600 boat days in 1953 to 6,002 boat days in 1958. During this period, fishing success per angler has remained fairly steady. An increased knowledge of the habits of the fish may be the key whereby the individual angler can increase his fishing success.

Appearing in the catch is another member of the herring family which is very similar in appearance and habit to the American shad called the hickory shad (*Pomolobus mediocris*). This species is slightly smaller than the American shad and is identified by its jet black tipped lower jaw which protrudes past the upper. Some fishermen who can identify these two fish claim the roe in the "hicks" is much sweeter and better eating than the roe of the other shad. Also, a small fish called summer herring (*Pomolobus aestivalis*) is often caught and misidentified as young shad. However, they are a separate species and when reaching maturity average about three-quarters of a pound in weight. The gizzard, or stink shad (*Dorosoma cepedianum*), is very numerous in this river, but is never taken with hook and line. This is the fish which was recently poisoned in Lake Apopka near Orlando, Florida, to make room for game fish.

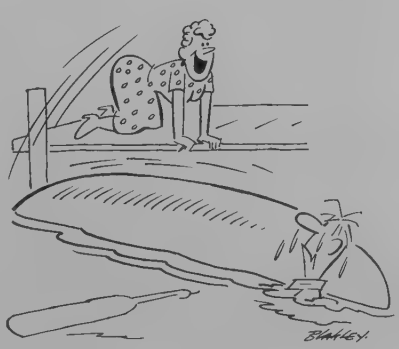
Access to the major shad fishing grounds is limited to nine landings located from the north end of Lake Monroe to the south inlet of Lake Harney, a distance of 25 miles. There are seven fish camps and two public landings.

All these camps are easily accessible from paved Florida State Highways. Guide boat service, boat handlers, motor and boat rental facilities are provided by most of these camps. The public landings are sponsored by local sportsmens' organizations and have parking facilities for several hundred cars and boat trailers.

Sport fishing for shad on the St. Johns is pursued almost exclusively by boat, with limited shore fishing in the Mullet Lake Area. Shad are taken by trolling or casting with various types of small metal spoons and weighted jigs. Shad are often caught on a single lure, but most fishermen prefer a combination of two lures, called a shad rig, which often results in a double catch.

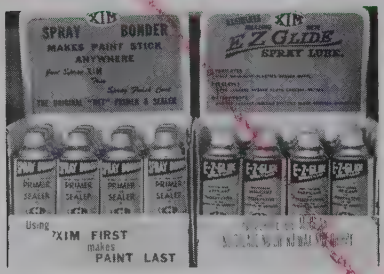
Man's interest in fish has two major phases — food and sport. In the St. Johns the shad can satisfy both. They will strike with rattlesnake tenacity, and they'll still be battling when taken aboard with a landing net. They are delicious in flavor, especially the roe smothered with bacon. These are the attributes that make shad so desirable.

Studies conducted on the St. Johns River shad since 1953 have indicated that the sport and commercial fisheries are not of a great enough magnitude, at least at the present time, to adversely affect the population. Investigations conducted on other Atlantic coast shad populations have shown, however, that it is possible to deplete a run by overfishing. So that this does not happen on the St. Johns, the U. S. Fish and Wildlife Service plans to continue its investigation of this fishery and to suggest management measures when and where found necessary. In this way the St. Johns River will continue to produce abundant quantities of shad and thereby enable future generations of Florida anglers to enjoy this new and exciting pastime. ●



"Tippy canoe?"

FLORIDA WILDLIFE FIELD TESTS AND TELLS



Outdoor equipment embraces a long list of varied name categories and includes many items of both general and specialized use, but all of it has one thing in common: It has to be given some degree of care if long, useful life is to be realized!

Even with the best of care, many of the items used by the active outdoorsmen occasionally or periodically need refinishing. Except where parts call for chemically-coloring or electroplating, most such refinishing involves some kind of a paint job. With some surfaces, like aluminum, glass, brass, galvanized and zinc coated metals, fiberglas boat hulls and plastics, getting a long last bond between applied paint and basic material is frequently a problem.

For those hard to do paint jobs on boats and other outdoor equipment, and for many specific uses around the home, FWFT&T recommends X-1-M Flash Bond Primer, product of H. Forsberg Company, Cleveland 14, Ohio, distributed in Florida by A. J. White, 425 Mango Lane, Jensen Beach, Florida.

X-1-M Flash Bond is a phenolic modified polyester synthetic coating practically clear in color. Applied according to directions to metal, fiberglas, masonite, plywood and similar hard to coat surfaces, X-1-M Flash Bond serves as a permanent adhesive between base material and the paint film. It has long had wide industrial use and is a familiar product to leading Florida boatbuilders, who use the preparation in many ways. FWFT&T's own tests have shown X-1-M Flash Bond primer coating to be a superior paint bonding and surface sealing agent. Until you have tried it yourself you will probably tend to unjustly classify X-1-M as "just another undercoating." (FWFT&T made that mistake, too.) . . . X-1-M Flash Bond is definitely different, being a product of a firm of more than 30 years experience in special paint manufacture and research. It is also easy to use; just spray it from its own powered container . . .

Another Forsberg product the sportsman should not overlook is E-Z Glide Lube, a liquid that literally gives smooth, ball bearing action to fishing reels, locks, hinges, firearms, machinery, clothing zippers and other items with moving parts, and preserves leather, rubber, cloth and other materials by waterproofing surfaces. The more you use E-Z Glide Lube, the more different uses you will find for the product, FWFT&T has found.

Try X-1-M Flash Bond primer when you next paint your boat, or have a specialized paint job, and give E-Z Glide Lube space in your tackle box and workshop. FWFT&T is confident that you will be pleased with results obtained from recommended trial.

To an archer, a strong, dependable bow string is a necessary and highly prized possession, for it is the greatly strained bow string that bends the ends of the bow and forces the arrow forward when the bowman draws an arrow for a shot.

If the bow string should break while the bow is being aimed at full draw, the sudden, uncontrolled force imparted to the bow can cause injury to the bow and possibly to the bowman. Desirably, a good bow string should be as thin as possible, but still possess a reserve of tensile strength that will delay immediate string breakage when signs of wear become evident. Serious archers make frequent and close inspection of the condition of their bow strings—especially where the loops fit the bow nocks and at the point where arrows are nocked for drawing to length.

Use of too heavy a bow string can make a bow feel sluggish in the hand and affect shooting performance. On the other hand, strings that lack a safety margin of tensile strength usually have short lives.

When a bowman finds a string of such twist or braid and strength that he enjoys peak performance from his bow and its matching arrows, he usually purchases several identical strings, and makes prompt replacement whenever a string shows signs of wear. Those who hunt with the longbow should always carry one or more extra strings in quiver compartment or coat pocket.

FWFT&T likes the construction and performance of the braided bow strings being marketed by the Newton Line Company, Homer, New York, a firm that has a background of more than forty years experience in the braiding of quality fishing line.

Braided of Fortisan-36 yarn, a material that has the lowest elongation or stretch of any of the synthetic fibers, the bow strings feature Lock-tite loops (a) both ends fit bow nocks and grooves perfect make bow stringing a much easier all sizes, the Newton bow strings unusual tensile strength and are rema resistant to abrasion. A special n resin finish makes the strings weath and desirably flexible.

Available in Light, Medium and weights, the new bow strings come i 54", 56", 57", 58", 59", 60", 61" 63", 64" and 66" lengths. Purcha weight and length recommended manufacturer of the bow you use.

If you can't find the Newton str local dealer stocks, drop a card manufacturer for descriptive literatu prices.

One secret of consistently takin pictures is to keep the camera len and spotless at all times. Trying to picture through a dirty camera lens viewing a pretty girl through fogge glasses; you simply do not get a tru effect picture!

Fingerprints on a camera lens can etch their outlines into the optical g time. Also, optical glass is easily sc by deposited dirt, and surface scratc cause diffraction of light that affect sharpness.

Many photographers take care blow or lightly brush away surface d then wipe the camera lens with cleaning tissue or a special dry clot

Better, still, is use of lens tissue drop of Edwal Protective Lens Cleane uct of Edwal Scientific Products Co West 11th Street, Chicago 28, Illino 85¢ for a bottle of sufficient size t 1,000 separate cleanings. A spec plicator-tip of the plastic bottle exactly one drop at a time to lens thus avoiding excessive fluid whic get between the lens components if in spray or stream. FWFT&T reco first putting a drop of the Edwal li a clean piece of lens tissue, and ther ing the moist spot to the camera le

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EXTREME LOSS IN BODY WEIGHT OF AN AMERICAN SHAD (*ALOSA SAPIDISSIMA*).—American shad (*Alosa sapidissima*) native to streams north of Cape Hatteras, North Carolina, do not normally die after spawning; and, if they survive natural and fishing mortality, return to their native stream to spawn in subsequent years (Talbot and Sykes, *U. S. Fish and Wildlife Service Fishery Bull. 58(142)*, 1958). Since they take little or no food from the time they enter the river, spawn, and return to the sea, they must subsist on the reserve energy accumulated in the form of fat and proteins.

Each spring shad enter the Connecticut River about the first week in April, and the run continues until mid-June. A dam at Holyoke, Massachusetts, 84 miles above the mouth, prevents migrating fish from passing this point. A mechanical fish-lift installed in 1955 passes several thousand shad each spring. Shad which spawn above this dam leave the spawning grounds by mid-July. The young hatched above the dam grow to four or five inches while in the river, then in fall, migrate to sea. Both adult and young on their downstream migration bypass the dam

Fig. 1. [upper] Preserved specimen of a four-year-old male American shad (*Alosa sapidissima*) from Connecticut River illustrating extreme loss in body weight after spawning and living a minimum of 120 days in fresh water; and [lower] Fresh specimen of a typical four-year-old male American shad (*Alosa sapidissima*) illustrating shad in pre-spawning condition.

through a canal system operated in conjunction with the dam.

In October, 1958, two adult shad were observed with the young in the canal system. Why or how these two adults were delayed in their downstream migration is unknown. One of these fish was captured during a mortality study conducted on downstream migrant juvenile shad. This adult fish was a four-year-old male which had spawned for the first time the previous spring (Fig. 1, upper). It weighed 1.0 pound and was 17.2 inches fork length. In contrast, the lower specimen is representative of a four-year-old male on its first spawning run. During the 1958 shad-fishing season the average weight and length of this age group in the Connecticut River was 3.2 pounds and 17.1 inches fork length, respectively.

It has been calculated that Atlantic salmon lose in body substance and in sex products discharged between 40 and 45 percent of their weight from the time they enter fresh water until they spawn. Death by starvation is known to occur in many animals when the loss in body weight exceeds 40 percent (Curtis, *Life Story o the Fish*, 1949; Krivobock, *International Counci for Exploration of the Sea, No. 63*, 1958) reporte that three-year-old spring-spawning salaka's (Bal tic herring) total loss of fat during the matura tion of the sexual glands and the spawnin amounted to 65.0 percent in 1956 and 52.4 per cent in 1957.

The spawned-out adult male shad capture after spending a minimum of 120 days in fres water had lost approximately 69 percent in bod weight. Examination of the liver showed that i had atrophied to less than 20 percent norma size and was faded yellow in color. The stomach had shrunk to less than 5 percent normal siz and was very hard. The gonads were very dar in color and hard-leathery in texture. Becaus of these morphological changes and loss in bod weight, it is doubtful that this fish could hav survived had it returned to the sea.—Paul R Nichols, *Bureau of Commercial Fisheries, U. S Fish and Wildlife Service, Beaufort, North Caro lina.*

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Uptake, Accumlation and Loss of Radioactive Cerium-144 by Marine Planktonic Algae[1]

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ABSTRACT

Following the uptake of an element by marine planktonic algae is difficult if the element occurs in both the ionic and particulate states. In this investigation the radioactive cerium (Ce^{144}) occurred mostly in the particulate state when added to sea water. The rate of formation of particles containing Ce^{144} was influenced by dilution, temperature, salinity, added cerium, and the presence of a chelating compound.

A culture of *Nitzschia closterium* containing dividing cells removed all the Ce^{144} originally added to the medium. Different species of algae concentrated cerium from 300 to 3000 times over amounts in the medium in a period of 30 minutes. After 24 hours all 6 species tested had concentrated cerium from about 2,000 to 4,500 times. Radioactive cerium continues to be taken up for as long as three days by non-dividing *Nitzschia* cells kept in the dark. The amount of cerium taken up by *Nitzschia* cells increased as the concentration of cerium in the medium was increased. Particulate cerium became associated with the cells at a faster rate than ionic cerium. The presence of a chelating compound in the medium resulted in a reduction in the uptake of Ce^{144} by *Nitzschia* cells.

Radioactive *Nitzschia* cells resuspended in nonactive medium lost about 25 per cent of their contained Ce^{144} in 5 hours. More Ce^{144} was lost from cells resuspended in 4 portions of nonactive medium, one after the other, than from cells remaining in the first portion of nonactive medium. A larger amount of Ce^{144} was lost from cells to medium containing a chelating compound. The greatest loss of Ce^{144} per unit of protoplasm in cells in nonactive medium was from "biological dilution." This loss amounted to ½ of the contained activity of the cells at each division.

INTRODUCTION

Radioactive fallout from the testing of nuclear weapons indiscriminately contaminates either the oceans, land, or both, depending upon existing meteorological conditions. Up to the present time probably the greatest quantity of fission products added to the oceans has come from weapon tests. Additional fission products in the oceans in the future will originate as wastes from laboratories, power reactors, and plants producing nuclear fuels and materials for nuclear weapons. With the possibility of increased contamination of the oceans with fission products there is a need for determination of the uptake, accumulation, and loss of individual radionuclides by marine organisms. These data can be used to predict the hazards of added radioactivity to marine populations and the possibility of different radionuclides passing through food webs and occurring in organisms harvested as food for man.

Cerium radionuclides contribute a large portion of the fission-produced materials occurring in sea water soon after the detonation of a bomb. This was shown by a radiochemical analysis on sea water collected near Bikini Atoll in June, 1954, following the hydrogen bomb tests which occurred during the period March to May, 1954 (Miyake and Sugiura 1955). Also, on land the greatest amount of radioactivity from fallout is contributed by the rare earth elements. The average of two complete soil assays, determined two years after the Marshall Islands were contaminated by fallout from the March 1, 1954, nuclear detonation of Operation Castle, gave 84% rare earths, 10% Ru^{106}, 5% Sr^{90}, and less than 1% Cs^{137} (Weiss *et al.* 1956).

The physical state in which an individual fission product occurs when added to sea

[1] The work reported was carried on as a part of a cooperative project of the U. S. Fish and Wildlife Service and the U. S. Atomic Energy Commission. Publication has been approved by these Agencies.

water controls to a great extent its mode of entry and subsequent assimilation by marine organisms. Greendale and Ballou (1954) determined the distribution of fission product elements among the soluble, colloidal, and particulate states by simulating in the laboratory an underwater detonation of an atomic bomb. Although there was some variation in duplicate trials, they found for cerium that approximately 2% was in the ionic state, 4% colloidal, and 94% particulate. Insoluble particles in the oceans can remain in suspension for considerable periods of time, depending upon the turbulence of the water, and can come in contact with surfaces upon which they can be adsorbed or attached (Donaldson *et al.* 1956, and Seymour *et al.* 1957).

In the oceans nonactive cerium occurs in a concentration of only 0.4 μg per liter of water (Goldschmidt 1937). The occurrence of radioactive particles in sea water to which radioactive cerium has been added may be due to the small concentration of nonactive cerium in sea water. This statement is based on a large number of researches which established that radiotracers in minute concentrations (generally 10^{-9} M and below) may exhibit a behavior similar to that of colloids (Schweitzer and Jackson 1952). These substances have been termed radiocolloids. Kurbatov and Pool (1944) have shown that cerium occurs as a radiocolloid.

Species of the filamentous algae, *Oscillatoria* and *Spirogyra*, in a lake contaminated by radioactive wastes concentrated radioactive rare earth elements to the same extent as radioactive phosphorus (Krumholz 1956). Much of this activity from rare earth elements could have been the result of an accumulation of radioactive cerium, since Steel and Gloyna (1955) have shown that freshwater algae in laboratory cultures can remove as much as 95% of the radioactivity contained in an inoculum of Ce^{141} to the culture.

Uptake of Ce^{144} by marine algae may be just as great as that of freshwater algae. This is indicated by findings of the Applied Fisheries Laboratory of the University of Washington (Donaldson 1955) showing that a large fraction of the radioactivity of the seaweeds, *Caulerpa* and *Halimeda*, collecte between March 26, 1954, and June 30, 195 at Rongelap Atoll, was due to Ce^{144}. Alsc planktonic algae take up large amounts c Ce^{144} as shown by radiochemical analysis c plankton collected during USAEC Opera tion Troll. Actually 80 to 90% of the ac tivity in these samples was due to Ce^{144} an its daughter Pr^{144}.

The purpose of the present investigatio was (1) to determine the physical state c Ce^{144} when added as a cerous nitrate solu tion to sea water, (2) to test the effect c certain factors upon the rate at whic particles of Ce^{144} are formed, (3) to measur the accumulation of Ce^{144} by marine plank tonic algae, (4) to compare the rates c uptake of ionic and particulate Ce^{144} b algae, and (5) to follow the loss of Ce^{1} from algal cells.

The authors wish to thank Dr. James F Lance for the *Platymonas* sp., Dr. M Fudinoga for the *Thalassiosira* sp., and D John H. Ryther for the *Amphidinium klebs* and *Porphyridium cruentum* cultures.

MATERIALS AND METHODS

The accumulation of radiocerium wa measured in the following planktonic algae

CHLOROPHYCEAE	DINOPHYCEAE
Carteria sp.	*Amphidinium klebsi*
Platymonas sp.	
BACILLARIEAE	RHODOPHYCEAE
Nitzschia closterium	*Porphyridium cruentum*
Thallassiosira sp.	

All species were in a high state of purity having been grown only in inorganic me dium, and thus were sufficiently free fro bacteria to make their use valid.

The culture medium used in all exper ments consisted of natural sea water en riched with Miquel's solutions (Rice 1953 This medium was filtered through a mill pore filter prior to using, and algal culture were grown in Erlenmeyer flasks of a ca pacity twice the volume of medium used After the appropriate number of cells an the desired amount of radioactivity ha been added to the medium, the cultures wer grown in a culture cabinet (Rice 1953) i

onstant illumination with daylight fluores-ent lamps at a temperature of 22 ± 2°C. The number of cells per liter was deter-ined after vigorously shaking the culture o distribute the cells evenly throughout he medium. The average of two cell ounts with an improved Neubauer haemo-ytometer was used to calculate the popula-on size.

The radionuclide, Ce^{144}, used in this in-estigation was supplied on authorization rom the Isotopes Division, United States tomic Energy Commission. It has a half-fe of 282 days and decays into prase-dymium-144, a radioactive daughter prod-ct with a half-life of 17½ minutes. It as obtained in the form of cerous nitrate n acid solution.

Radioactivity of samples was measured ith an end-window Geiger-Müller tube nd a conventional scaler. If separation of Ce^{144} and Pr^{144} had occurred, time was llowed for their return to secular equi-brium before determining the radioactivity n the sample. Appropriate corrections ere made for geometry, coincidence, back-round, and decay. Sample thickness was uch that no correction for self absorption as necessary. Results presented are based n duplicate samples. Details of sample reparation will be given as the various xperiments are described.

EXPERIMENTAL RESULTS

Most previous investigations of the up-ake of inorganic materials from sea water y plantonic algae have been limited to lements present in the ionic state. In this nvestigation it will be shown that cerium ccurs in sea water in both the ionic and articulate states. This makes it difficult o determine the relative importance of the ifferent mechanisms responsible for the bserved uptake. No doubt the ionic and articulate components are not equally vailable for uptake by the cells. Since the Ce^{144} in fallout may be in a different chemi-al combination from the Ce^{144} used in this nvestigation, experiments have been in-luded to show that the addition of Ce^{144} as erous nitrate to sea water results in the ormation of radioactive particles. Also, the rates of formation of these particles will be shown to vary with experimental conditions.

Factors influencing the formation of Ce^{144} particles in sea water

The physical state of Ce^{144} was determined by filtering sea water to which radioactive cerium as cerous nitrate had been added. Any radioactivity on the filter could result from Ce^{144} in the ionic state being adsorbed or from the retention of particles containing Ce^{144}. If only radioactivity from particles is retained on the filter, the rate of formation of particles can be followed easily and accurately. A certain amount of ionic Ce^{144}, theoretically, would be required to completely saturate the filter pad by surface adsorption. Thus there would be no further increase of radioactivity as additional volumes of sea water culture medium are filtered. If adsorption does not contribute significantly to the activity retained on the filter, particles equally distributed throughout the medium would be retained in direct proportion to the volume of medium filtered.

To measure changes in the radioactivity of the filter, volumes of 10, 20, 30, 40, 50, and 60 cc of medium, containing 6.2 microcuries of carrier-free Ce^{144} per liter, were each filtered through a separate millipore

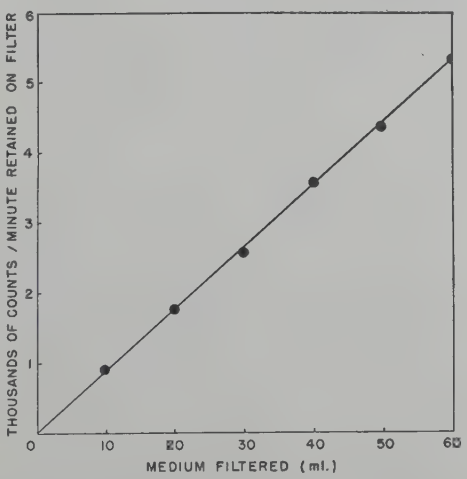


FIG. 1. Radioactive cerium retained on millipore filter from culture medium.

filter. Activity retained on the filters formed a straight line when plotted against the volume of medium filtered (Fig. 1). It can thus be concluded that the addition of Ce^{144} in the form of cerous nitrate to sea water culture medium results in the formation of particles which can be filtered from the medium. The radioactivity of the filter is due to particles of Ce^{144} and not to adsorption of Ce^{144} ions.

A number of factors were tested that might be in operation in the oceans or enter into laboratory experiments to influence the rate of formation of particles of Ce^{144}. These include dilution, temperature, salinity, the concentration of cerium, and the addition of a chelating compound.

Dilution. The effect of dilution was determined by adding 5 microcuries of Ce^{144} to each of 3 different volumes of culture medium (Table 1). The greater the dilution of Ce^{144}, the larger was the per cent of Ce^{144} occurring in the particulate state.

Temperature. There was a faster rate of particle formation at 22.6°C than at 3.1°C (Table 2).

Salinity. Since the quantity of salts present in water may influence the amount of Ce^{144} occurring in the particulate state, sea water was diluted with distilled water to give several salinities (Table 3). At some salinities there appeared to be a slight increase in the amount of Ce^{144} occurring in the particulate state. However, the greatest amount of Ce^{144} occurred as particles in the distilled water, which was also tested.

Concentration of cerium. Adding increased amounts of cerium, as cerous nitrate to the medium resulted in a greater amount of the Ce^{144} being retained as particles on the filter (Table 4).

Chelation. The addition of a chelating compound such as Versene, which is the sodium salt of ethylene-diamine-tetraacetic acid, to culture medium resulted in a smaller percentage of Ce^{144} being retained on the filter (Table 5).

TABLE 1. *Effect of diluting Ce^{144} in sea water upon the percentage retained as particles on a filter*

Hours	Volume (ml)		
	250	1000	3000
0.5	6.5	21.9	42.8
24.0	15.7	40.2	100.0

TABLE 2. *Percentage of Ce^{144} retained on a filter as particles from medium kept at different temperatures*

Hours	Temperature (centigrade)	
	3.1°	22.6°
2.5	4.0	9.4
5.5	4.7	10.2
10.0	7.3	17.0
24.0	7.0	14.2

TABLE 3. *Percentage of Ce^{144} retained on a filter as particles from medium with different salinities*

Salinity ‰	Hours	
	2	24
36	6.4	9.9
31	7.2	8.1
26	6.6	7.6
20	6.8	11.5
15	7.9	10.6
10	9.4	12.8
5	11.6	16.4
*0	41.1	38.9

* Distilled water

TABLE 4. *Percentage of Ce^{144} retained on a filter as particles from medium containing different amounts of nonactive cerium*

Hours	Added cerium (μg)		
	0	57	900
0.5	5.3	38.6	100.0
24.0	8.2	100.0	100.0
96.0	16.2	100.0	100.0

TABLE 5. *Effect of Versene upon the percentage of Ce^{144} retained on a filter as particles from medium*

Hours	No Versene added	0.1 g Versene added
0.5	31.1	1.5
21.0	37.3	2.2
45.0	36.2	3.8
69.0	34.9	3.0
93.0	33.1	2.9

nportance of "growth" of particles containing Ce^{144} on the rate of removal of Ce^{144} from sea water

The rate at which Ce^{144} occurs in the rticulate state may be speeded up by the growth" of particles formed immediately on addition of Ce^{144} to the medium. To easure the influence of these particles upon e total amount of Ce^{144} removed by filter-g, one of two identically prepared volumes culture medium was filtered just after lding the Ce^{144}, while the other volume of edium was not filtered. When the filtered edium was again filtered, much less Ce^{144} as retained on the filter, only 1 to 2% oc-rred as particles. By comparison, an in-ease of 14% of Ce^{144} from the unfiltered edium was retained as particles. Since e formation of new particles in these two olumes of medium probably occurred at out the same rate, it can be concluded at the "growth" of particles formed im-ediately upon adding the Ce^{144} to the edium is more responsible for the occur-nce of Ce^{144} in the particulate state with me than is the formation of new particles.

Uptake of Ce^{144} by Nitzschia *cells*

Since the addition of the radioactive Ce^{144} s cerous nitrate to culture medium results the formation of particles, it was neces-ry to use a method of removing cells from e medium which would exclude as much e^{144} not associated with the cells as pos-ble. The per cent of Ce^{144} in medium that n be removed by centrifuging was deter-ined and compared with that removed by ltering. Also, the loss of Ce^{144} from me-ium with time due to adsorption on the alls of the culture flasks was measured, nce the experiments on the uptake of Ce^{144} y phytoplankton were to be followed for everal days.

The culture medium used in this experi-ent contained 6.8 microcuries of Ce^{144} per ter. Periodically, samples of 5 cc each ere removed, evaporated to dryness, and he contained activity determined. Also, amples of 25 cc each were centrifuged, while ther duplicate samples were filtered. The entrifuged medium was decanted, and the entrifugate was suspended in nonactive medium and filtered on a filter pad, so that the activity centrifuged from the medium could be measured.

TABLE 6. *Loss of Ce^{144} with time from culture medium in a standing culture and by centrifuging and filtering*

That lost by centrifuging and filtering is based on the amount remaining in the standing culture medium at the time of testing.

Days	Percentage Ce^{144} lost from medium		
	Standing culture	Centrifuging	Filtering
0			5.9
7	15.0	1.7	7.7
10	24.0	2.6	8.0
14	31.7	3.1	7.8
18	34.2	8.2	8.5

Radioactivity continued to be lost from the medium to the sides of the flask upon standing (Table 6). For the first 14 days only 2 to 3% of the activity remaining in the medium was lost by centrifuging. After 18 days the amount lost by this method had increased to over 8%. The per cent of activity removed by filtering did not vary much over the entire period of time tested. From the data presented in this table it is obvious that centrifuging is the better method for separating cells from the radioactive medium during the first 14 days. In the remaining experiments Ce^{144} in cells was determined by centrifuging the cells from either 25 or 40 cc of medium, decanting the active medium, resuspending the cells in nonactive medium, filtering the cells on a millipore filter, and measuring the Ce^{144} in the cells.

In cultures not shaken. The uptake of Ce^{144} from culture medium by dividing cells was followed in a culture started with 4×10^7 *Nitzschia* cells and 6.2 microcuries of Ce^{144} per liter. A control culture to which no cells were added was started with the same amount of Ce^{144}. The activity remaining in the medium of the control was determined at the same time the *Nitzschia* culture was sampled.

The curve representing the counts per minute associated with cells (Fig. 2) follows rather closely the curve representing the number of cells present. There was

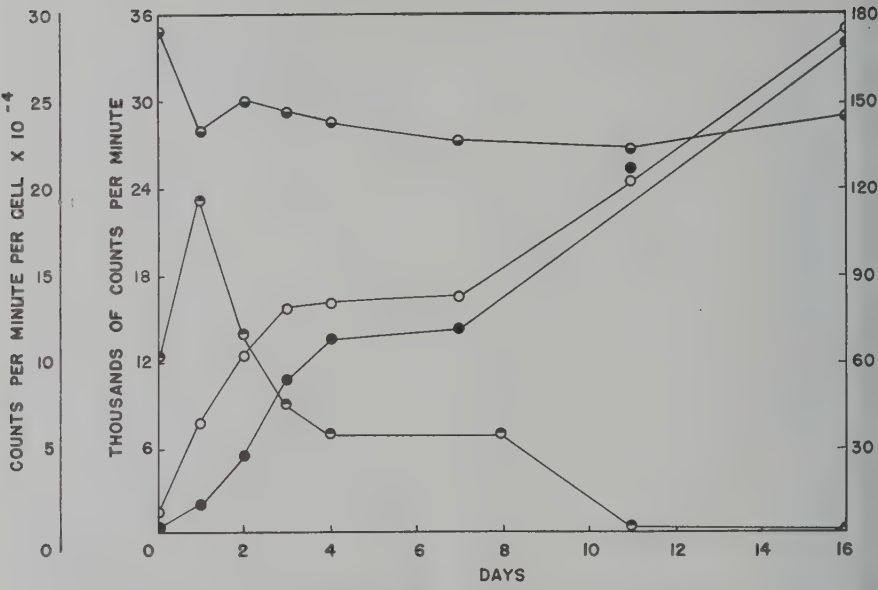


FIG. 2. Uptake of Ce^{144} by dividing *Nitzschia* cells and loss of Ce^{144} from medium of the contr
◒ Counts per minute contained in 40 cc. of medium from control culture
○ Counts per minute in cells from 40 cc. of medium
● Population growth curve of *Nitzschia* cells
◔ Counts per minute per cell

very little increase in the number of cells or the uptake of activity from the fourth day until after the seventh day. The factor or factors responsible for this are not known. The amount of activity in the cells on the sixteenth day represents almost all that was present in the medium at the beginning of the experiment. This uptake by the cells occurred, even though the activity remaining in 40 cc of medium of the control on this date had decreased from about 34,500 to 29,100 counts per minute. The cells removed the activity at a sufficient rate to prevent much from being adsorbed or attached to the walls of the flask. The greatest amount of activity per cell occurred at the end of 24 hours.

In cultures shaken. Forces that enhance the mixing of sea water in the oceans will also increase the chances of phytoplankton and particulate material coming in contact. This may speed up the association of Ce^{144} particles with phytoplankton cells. To measure in the laboratory the effect of mi ing on the rate of uptake of Ce^{144} from t medium, some cultures were shaken for minutes on an automatic shaker, whi others were not. The *Nitzschia* cultur were started with 24×10^7 cells and 5 microcuries of Ce^{144} per liter. Controls we also prepared with the same amount Ce^{144} in the medium, but containing cells. Some controls were shaken for minutes on the automatic shaker whi others were not.

The Ce^{144} in the medium of the contr that was shaken decreased 37% more tha in medium which was not shaken. Th was probably due to more Ce^{144} coming contact with the sides of the flask and bei adsorbed in greater amount in the shak than in the unshaken control. *Nitzsch* cells in the shaken cultures took up 39% the activity in the medium, while cells the unshaken cultures removed 30%. Ho ever, since there was less Ce^{144} remaini

in the medium in the cultures that were shaken, the cells in the unshaken cultures contained more Ce^{144}.

Concentration of Ce^{144} by planktonic algae

In the previous experiment considerable Ce^{144} was taken up by the *Nitzschia* cells in only ½ hour, while the greatest amount of activity per cell occurred at 24 hours. The extent to which Ce^{144} was concentrated at these time intervals and under the same experimental conditions by six species of algae was determined. The concentration of activity by the algae was calculated on a wet weight basis following the method described by Rice (1956), except that the cells were centrifuged from the medium. At the end of only ½ hour some of the cells had concentrated Ce^{144} from about 2,000 to 3,000 times over amounts occurring in an equal weight of medium (Table 7). After 24 hours all algae had concentrated the radionuclide from about 2,000 to almost 4,500 times.

In all further experiments *Nitzschia closterium* cells were used, since at the end of 24 hours the *Nitzschia* cells had concentrated Ce^{144} the least of all species. Thus following the uptake of Ce^{144} by *Nitzschia* cells under the various experimental conditions would more nearly approximate the least amount of Ce^{144} accumulated by these species of planktonic algae.

Uptake of Ce^{144} by various population sizes of Nitzschia *cells*

Since there is always a standing crop of phytoplankton in nature which can remove part, if not all, of any radionuclide introduced into the oceans, the immediate uptake of Ce^{144} by various population sizes of *Nitzschia closterium* was tested. Population sizes of 48, 83, 157, 313, and 625 × 10^7 cells per liter were used to start cultures containing 3 microcuries of Ce^{144} per liter. Also another series of cultures was prepared in the same manner, except these cultures contained 1.5 microcuries of Ce^{144} per liter.

TABLE 7.[1] *Number of times cerium is concentrated over the amount in sea water by planktonic algae*

Algae	Concentration of Ce^{144}	
	0.5 hours	24 hours
Carteria sp.	314	2,422
Platymonas sp.	1,843	2,127
Nitzschia closterium	518	1,970
Thalassiosira sp.	2,610	3,346
Amphidinium klebsi	3,001	4,498
Porphyridium cruentum	802	3,344

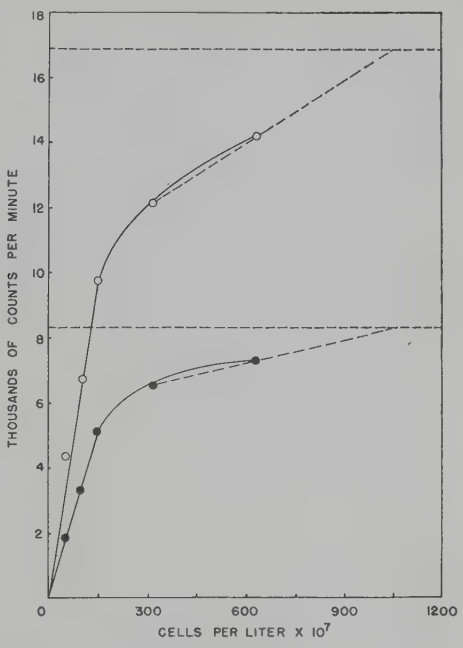


FIG. 3. Uptake of Ce^{144} by different population sizes of *Nitzschia* after 30 minutes in active medium.
- ○ Populations of cells in medium containing 3 microcuries Ce^{144} per liter
- ● Populations of cells in medium containing 1.5 microcuries Ce^{144} per liter

The uptake of Ce^{144} in 30 minutes by the different population sizes in cultures containing the two concentrations of activity followed the same pattern, as shown in Figure 3. In cultures containing the largest population size about 85% of the Ce^{144} was removed from the medium by the cells. From these curves it can be concluded that population sizes of a million or less, which ordinarily occur in nature, or even larger populations such as those during blooms, would not immediately remove a very large

amount of the Ce^{144} added to the water. To estimate the smallest population size of *Nitzschia* cells which might conceivably remove all the Ce^{144} from the medium, a straight line was drawn in Figure 3 between the last two points, and extended on to the dotted line representing the activity originally added to the medium from which the cells were removed. The population size required to remove all the Ce^{144} from the medium would actually be larger than this population of about $1{,}050 \times 10^7$ cells per liter, since the curve tends to level off as the number of cells increases. From this experiment it can be concluded that the immediate uptake of Ce^{144} by a population of phytoplankton which might occur in the oceans would represent a small percentage of that added to the water.

Uptake of Ce^{144} by non-dividing Nitzschia *cells*

In the oceans under adverse conditions, such as too low a temperature, a shortage of nutrients, or the lack of sufficient light, phytoplankton may not divide or do so very slowly. To measure the removal of Ce^{144} by populations of non-dividing *Nitzschia* cells, cultures were prepared with cells that had been kept in the dark until cell division had ceased. Cultures were then started with either 26, 51, or 102×10^7 cells per liter in medium containing 30 microcuries of Ce^{144} per liter. During the experiment the cultures were retained in the dark to prevent the cells from dividing.

The amount of activity taken up by the cells in ½ hour did not increase in proportion to the number of cells present (Table 8). Activity continued to be removed from the medium by all three population sizes for 72 hours. At this time the uptake of activity by the largest population of cells ceased with about 50% of the Ce^{144} having been removed from the medium.

TABLE 8. *Percentage uptake of Ce^{144} by non-dividing Nitzschia cells at different population sizes and after various exposure times*

Population size (10^7 cells/liter)	Hours				
	0.5	24	48	72	144
26	6.1	16.2	21.9	32.4	34.7
51	12.2	24.9	32.4	40.0	47.7
102	16.6	30.2	35.6	49.2	48.6

Effect of carrier cerium on the division rate of Nitzschia *cells and on the uptake of Ce^{144} by them*

It has been shown for many elements that uptake by planktonic algae increases as the concentration of the element in the medium increases, when other factors are kept constant. However, high concentrations of some elements have been found to reduce the division rate of algal cells. Thus the effect of increased concentrations of cerium upon the division rate of *Nitzschia* cells was determined in concentrations of 1, 4, 16, 57, 230, 919, 3,678, and 14,713 μg cerium per liter of medium added as cerous nitrate.

Only the highest concentration of cerium appeared to have any effect on reducing the division rate. All cultures were started with the same number of cells and were grown for 10 days in medium containing the added cerium. The medium with the highest concentration of cerium had a pH of 6.93. It is known that this is an unfavorable pH for the growth of these cells, which

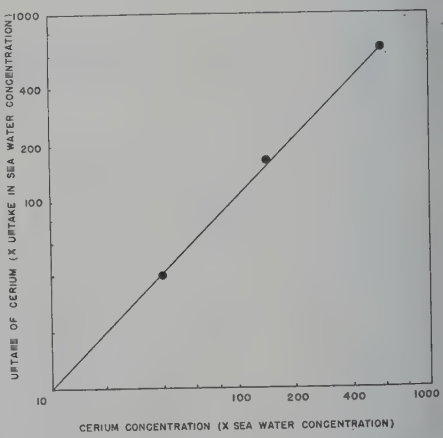


FIG. 4. Uptake of cerium by *Nitzschia* cells grown in medium containing increasing amounts of cerium. (For example, cells grown in medium containing 40 times as much cerium as present in sea water take up 40 times more cerium than when grown in the sea water concentration.)

may partially account for the reduced division rate observed. The next highest concentration of cerium, 3,678 μg per liter, is several thousand times greater than that normally occurring in sea water and probably would never exist in the oceans.

The uptake of cerium by cells in medium with concentrations of cerium equal to 40, 143, and 575 times that occurring in sea water was followed for 7 days. The uptake of cerium increased as the concentration of cerium in the medium increased (Fig. 4). This increase was proportional to the amount of cerium added; for example, if the cerium concentration was increased 40 times over sea water concentrations, cells grown in this medium took up about 40 times more cerium than cells grown in culture medium without added cerium.

Comparison of the rates of uptake of ionic and particulate Ce^{144} by Nitzschia *cells*

It has already been pointed out that the cerium radionuclides occur mostly in the particulate state in the oceans. Also, the removal of a part of the Ce^{144} by filtering and centrifuging is evidence that some of it occurs in a particulate state. Actually, it was found that almost all of the Ce^{144} remaining in a four-month-old volume of culture medium could be removed by filtering. Thus, in this medium all the Ce^{144} was considered to be in a particulate state. Uptake of activity by *Nitzschia* cells from this medium would indicate the rate of uptake of particulate Ce^{144}.

In order to obtain Ce^{144} in the ionic state, 0.5 cc of a solution of Ce^{144} was placed in a semipermeable membrane bag and immersed in a 250-cc volume of culture medium. The medium was stirred constantly, and at intervals 5-cc portions were removed, evaporated to dryness in a plastic Petri dish, and the activity in the sample was measured. There was a rather rapid rate of passage of 12.5% of the Ce^{144} through the membrane bag (Fig. 5).

Upon dialyzing into the culture medium the ionic Ce^{144} might form particles before sufficient amounts could be obtained to follow its uptake by the cells. To reduce the possibility of this occurring, *Nitzschia* cells were placed in the medium into which the semipermeable membrane bag was immersed. Under these conditions it would be possible for the cells, if they possessed the capacity, to take up the ionic Ce^{144} as it passed from the semipermeable membrane bag into the culture medium.

Uptake of Ce^{144} from medium under these conditions and from medium containing all the Ce^{144} in the particulate state was followed from 250-cc volumes of medium containing 12×10^7 *Nitzschia* cells per liter. Both volumes of medium were stirred continuously. In these uptake experiments a new

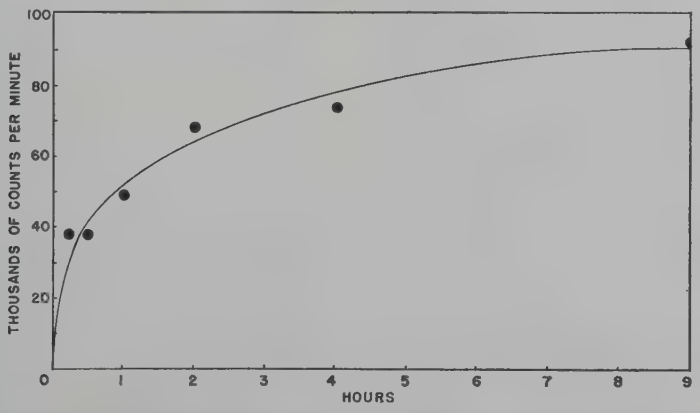


FIG. 5. Dialysis of Ce^{144} into culture medium from a semipermeable membrane bag which contained an initial activity of 740,000 counts per minute.

volume of medium was used for each time interval.

The particulate Ce^{144} was taken up by the cells at a faster rate than the ionic form (Table 9). The one-half hour uptake of ionic Ce^{144} was not determined. Also, the uptake of the cerium radionuclides in the oceans may occur at a very rapid rate, since Greendale and Ballou (1954) found 98% of the cerium radionuclides in the particulate and colloidal states by simulating conditions of an underwater detonation of an atomic bomb.

Uptake by Nitzschia *cells of* Ce^{144} *from medium containing a chelating substance*

In a previously discussed experiment Versene was found to reduce the amount of Ce^{144} occurring as particles in the medium. Since it has already been observed that particles are taken up faster than the ionic material, it was of interest to follow the effect of Versene on the uptake of Ce^{144} by *Nitzschia* cells. Cultures with 4×10^7 cells and 8 microcuries of Ce^{144} per liter were prepared. One culture was retained as a control and no Versene was added to it. To one culture 0.025 gram of Versene per liter was added, to another culture 0.05 gram per liter, and to a third culture 0.1 gram per liter of Versene was added.

The uptake of Ce^{144} by *Nitzschia* cells in all three cultures containing Versene was less for the first three days than that taken up by cells in the control culture (Table 10). After 93 hours the total amount of Ce^{144} taken up by the cells in the control and in the cultures with the two smallest concentrations of Versene was not significantly different. However, less activity was taken up by the cells in the culture containing the largest concentration of Versene than in any of the other cultures.

Loss of Ce^{144} *from* Nitzschia *cells*

When only a single addition of fission products is made to the ocean or when long intervals of time occur between additions, phytoplankton might not be important in passing Ce^{144} to higher trophic levels. This would be true only if the cells could not retain most of the activity taken up. Even though Ce^{144} is concentrated many times over amounts in sea water and may not be lost again to the sea water, it is still possible for the cells through their own division to dilute the activity in their protoplasm. This reduction of activity in the protoplasm by division of cells in water containing no activity is referred to as "biological dilution."

TABLE 9. *Percentage uptake of ionic and particulate* Ce^{144} *by Nitzschia cells with time*

Hours	Ionic	Particulate
0.5		52.4
9.0	36.3	83.0
24.0	56.9	84.6

TABLE 10. *Effect of Versene in the medium on the percentage uptake of* Ce^{144} *by Nitzschia cells*

Hours	No Versene added	Versene added		
		0.025 g/L	0.05 g /L	0.1 g /L
0.5	7.8	0.3	0.1	0.1
21.0	29.8	1.3	0.8	4.8
45.0	37.0	8.9	5.4	1.8
69.0	32.5	27.0	22.7	8.3
93.0	31.3	32.4	33.4	25.5

Dividing cells resuspended in nonactive culture medium. The loss of Ce^{144} to the medium from dividing *Nitzschia* cells was found to be small. Cells were first grown for 10 days in culture medium containing 6 microcuries of Ce^{144} per liter. They were then centrifuged from the active medium and resuspended in nonactive medium. This culture was divided into ten 100-cc cultures and placed in the culture cabinet where cell division would continue. The activity in both the cells and medium was measured periodically over a period of 42 days, and the percentage of activity in the medium was calculated.

The greatest amount of activity occurred in the medium at the time the first sample was taken (Table 11) and continued to decrease for the next seven days. After this time there was not much change in the amount of activity occurring in the medium. While the cells immediately lost about 25% of their original activity to the medium, at 42 days they had lost about 80%, mostly by "biological dilution." During the 42 days the cell population increased from 36×10^7 to 205×10^7 cells per liter, or there was a

ABLE 11. *Loss of Ce^{144} from active cells to the medium*

Days	Population size (10^7/cells/liter)	Percentage Ce^{144} in medium
0.2	36	25.2
1.0	35	17.9
4.0	68	12.7
7.0	85	7.2
14.0	91	6.5
21.0	94	9.4
28.0	172	8.2
36.0	180	3.4
42.0	205	6.4

ABLE 12. *Loss of Ce^{144} from cells to medium in repeated washings*

Washings	Percengage Ce^{144} lost to medium
1	7.7
2	8.1
3	7.2
4	8.2

ABLE 13. *Increased loss of Ce^{144} from Nitzschia ells as a result of adding Versene to the medium*

Hours	Percentage
1	3.9
4	16.8
24	31.1
48	21.6
96	19.1

otal of 2.42 divisions. With a 50% reduction in activity in a cell at each division, fter this number of divisions a cell would ontain only about 18% of its original activity.

Cells centrifuged and resuspended in sequence in four different volumes of medium. adioactive phytoplankton floating in nonctive sea water are continually being bathed "new" sea water. In the previous experiient it was found that a 25% loss did occur om the cells but, while the dividing cells emained in the same medium, there was no rther loss to the medium. In this experiient *Nitzschia* cells containing Ce^{144} were spended in nonactive medium for 30 minutes, centrifuged from this medium, and the rocess repeated three times. There was bout an 8% loss from the cells during each f the four washings (Table 12).

Cells resuspended in culture medium containing a chelating substance. The loss of Ce^{144} from *Nitzschia* cells resuspended in culture medium with Versene was compared to that from cells in culture medium containing no added Versene. The *Nitzschia* cells were made radioactive with Ce^{144} by growing them for five days in culture medium containing 7.9 microcuries of Ce^{144} per liter. These cells were centrifuged from the active medium and resuspended in nonactive medium. This culture was divided into two cultures and 0.5 g of Versene per liter was added to one. Samples of 25 cc were removed from each culture periodically. The cells were centrifuged from the medium, and the activity lost to the medium was measured. There was a greater loss of Ce^{144} from cells suspended in medium to which Versene had been added (Table 13).

DISCUSSION

Even though the composition of fallout which descends upon land is the same as that which falls upon the oceans, its uptake by terrestrial plants is quite different from that of marine planktonic algae. For example, the radionuclide, Cs^{137}, which occurs in very small amounts in fallout, is responsible for most of the radioactivity found in the edible portion of terrestrial plants after the soil has been contaminated by fallout (Weiss *et al.* 1956). Planktonic algae, as will be reported in detail elsewhere, concentrate Cs^{137} only 1 to 3 times over amounts present in sea water in which they are grown. Also there is a difference in the uptake by terrestrial plants and planktonic algae of the radionuclide Ce^{144}, which occurs in large amounts in fallout. It has been reported that only negligible amounts of Ce^{144} are taken up by terrestrial plants (Neel *et al.* 1953), while in this investigation it has been shown that planktonic algae concentrate Ce^{144} from 3,000 to 4,500 times.

Why does Cs^{137} occur in such large amounts in the plants when present in such small quantities in the soil, and why do the rare earth elements occur in the plants in such small amounts when present in such large amounts in the soil? This difference in uptake may not necessarily indicate any difference in nutritive requirements for these elements, since the uptake of fission products

from the soil by plants appears to be a function of their solubility (Larson *et al.* 1953). Insoluble particles resulting from the bomb blast may not readily migrate through the soil and therefore could not come in contact with the roots. Weiss *et al.* (1956) do not agree with the argument that Cs^{137} was made available to the root system of the plants in greater concentration by preferential translocation through the soil. During a one-year interval between two measurements they found that the amount of Cs^{137} in relation to other nuclides in the upper layer of the soil remained essentially unchanged. It is our belief that this observation can partially be explained on the basis that the Cs^{137} and other soluble radionuclides have the longer half-lives; thus the greatest loss is from leaching. The rare earth elements and other less soluble radionuclides have much shorter half-lives, making the greatest loss due to decay. It could, theoretically, be possible that the loss due to leaching might equal the loss by decay, giving no apparent change in the relationship of Cs^{137} to other radionuclides. It still remains an indisputable fact that a radionuclide can not be taken up from the soil by a terrestrial plant until it occurs in the root zone area.

Cerium-144 has been found to occur mostly in the particulate state in sea water, and it was further demonstrated that dilution, temperature, salinity, and added cerium carrier all influence the amount of Ce^{144} occurring in the particulate state following its addition to sea water. Since Ce^{144} occurs as particles in sea water, the measurement of the rate at which it became associated with phytoplankton required that cells be separated from sea water by centrifuging.

Since Ce^{144} added to sea water occurs in both the ionic and particulate states, there may be at least two methods by which it becomes associated with phytoplankton cells. Ionic Ce^{144} was taken up by *Nitzschia* cells either by being taken into the cells or being adsorbed on their surfaces. Particulate Ce^{144} became associated with the *Nitzschia* cells as a result of particles and cells coming in contact with each other and sticking, as confirmed by the continued uptake of Ce^{144} by non-dividing cells kept in the dark.

That particles do become associated with phytoplankton cells has been known for several years. Harvey (1937) found that particles of ferric hydroxide collect on the surface of diatoms. He believed it very unlikely that this coming together of ferric hydroxide particles and phytoplankton was the result of electrostatic attraction. He suggested that the particles "just stick" when coming in contact with the cells, which in many instances have a mucilaginous-covered surface. Also, Goldberg (1952) demonstrated that particulate and colloidal forms of iron are utilized in the metabolism of *Asterionella japonica.*

The mixing of water in the oceans would bring the phytoplankton cells and any added Ce^{144} particles into contact more frequently than occurs in standing cultures in the laboratory, resulting in a more rapid uptake. In the laboratory *Nitzschia* cells in cultures shaken continuously took up a larger percentage of the Ce^{144} from the medium than cells in identical cultures not shaken. However, the loss of Ce^{144} by adsorption to the sides of the flask in the shaken cultures was so great that cells in the unshaken cultures actually contained more Ce^{144} than those in the shaken cultures.

It has been suggested by several investigators that phytoplankton are not important in the removal of radionuclides from sea water when these nuclides occur in the particulate state, such as following a bomb explosion. Their opinion is that zooplankton, being filter feeders, concentrate the activity by filtering the radioactive particles from the water. In this investigation it has been shown that phytoplankton can rapidly concentrate added Ce^{144} when it is present in the water as particles. In 24 hours different species of phytoplankton were found to have concentrated Ce^{144} from about 2,000 to 4,500 times over that in sea water. In contrast we found that adults of a copepod species, *Tigropus californicus* (Baker), in 24 hours concentrated Ce^{144} only 76 times over sea water concentrations, while adults of *Artemia salina* (L.) concentrated Ce^{144} about 167 times over sea water concentrations in the same period of time (experimental results to be reported elsewhere).

Since these experiments were conducted

r only 24 hours, one might suspect that the ncentration factor for cerium in zooplank- n would increase with time, while a de- ease might occur in the concentration ctor of the phytoplankton. We believe at this reasoning would be incorrect since oplankton, if similar to other animals, do ot metabolize the rare earth elements to ıy great extent. Most of the Ce^{144} in the oplankton would either be in the filtering echanism or in the gut. Thus, there would robably be no long term retention of the rticles by the zooplankton unless the Ce^{144} as continuously available. Also, the num- er of Ce^{144} particles in the water would ecrease with time as a result of dilution by ıe mixing of the water and by accumula- on by living organisms, so that it would be ıore and more difficult for the zooplankton accumulate radioactive particles from the ater. As for the phytoplankton, it is be- eved that the amount of Ce^{144} concentrated y the cell would be controlled by the divi- on rate of the cells in relation to the Ce^{144} emaining in the water. If the uptake of Ce^{144} by phytoplankton were lessened due to reduction in the availability of Ce^{144} in the ater, the amount of Ce^{144} per cell would be ontrolled more by the rate of division of ıe cell. Thus, there is no reason to sus- ect that the Ce^{144} would decrease at a faster ate with time in phytoplankton than in oplankton.

Steel and Gloyna (1955) followed the up- ake of Ce^{141} by algae under laboratory con- itions in experimental oxidation ponds. rom these studies they concluded that adioactive cerium will be completely re- ıoved from the water in the ponds, if condi- ions are suitable for growth of the algae and he ponds are properly operated.

In the present investigation it was found hat a *Nitzschia* culture started with a rela- ively small number of dividing cells would emove all the Ce^{144} from the sea water me- ium in 16 days. In this period of time a ingle dose of Ce^{144} added to the oceans ould be rapidly diluted by currents and he mixing of the water. Probably this ilution would occur at least as rapidly as he phytoplankton could concentrate the Ce^{144}. In experiments reporting the uptake f Ce^{144} by various population sizes of *Nitzschia* it was shown that the number of cells required, in laboratory cultures, to re- move all the Ce^{144} from the medium was many times larger than populations ever en- countered in nature. Other uptake experi- ments not included in the experimental results with natural population sizes of plankton collected in water taken about 3 feet below the surface off the laboratory dock revealed that from 10 to 24% of the Ce^{144} added to this water was taken up by the plankton in ½ hour. From 44 to 54% was removed if the plankton collections were placed in the light in the culture cabinet for 24 hours. Natural populations of plankton in water taken 5 to 10 miles offshore removed not over 7% of the Ce^{144} in ½ hour and only 22% in 24 hours.

If radioactivity were added to sea water in a single dose and large amounts of it were rapidly taken up by the phytoplankton cells, these cells would be very important in pass- ing the activity to higher trophic levels. However, it has already been demonstrated that time which would allow for dilution is necessary in the removal of Ce^{144} from sea water by planktonic algae. In the oceans other factors, with time, would reduce the amount of Ce^{144} in the water, so that it is difficult to assign the overall relative im- portance of phytoplankton as a potential concentrator of Ce^{144} and supplier of it to higher trophic levels. However, 9 to 10 months following the nuclear tests in the Pacific, radioactivity was found associated with plankton in the upper water mass (USAEC Operation Troll).

Also, after the radioactivity has been com- pletely removed from the water by one process or another, the phytoplankton with the passage of time become less and less radioactive and thus are not as important in getting their contained activity into higher trophic levels. This is due to "biological dilution" or the reduction by cell division of activity per unit weight of protoplasm. If conditions are suitable for rapid cell division the radioactivity can be drastically diluted in a relatively short period of time, since a 50% reduction of activity per cell occurs with each division.

Actually it is not necessary that the ac- tivity be completely removed from the water

before "biological dilution" comes into operation. Soon after the addition of a single dose of activity to sea water, it is reduced to a concentration where enough is not available to maintain the same rate of uptake. If cell division continues at the same rate or increases, then "biological dilution" occurs.

Since phytoplankton can concentrate Ce^{144}, different food chains or webs might be involved in getting this nuclide to higher trophic levels than would be expected if zooplankton were the primary concentrator. It can be concluded that phytoplankton are important in passing particles of Ce^{144} from the water to higher trophic levels.

REFERENCES

Donaldson, Lauren R. 1955. A radiological study of Rongelap Atoll, Marshall Islands, during 1954–1955. Univ. Washington, Applied Fish. Lab. Rep. No. UWFL-42. 46 pp.

Donaldson, Lauren R., Allyn H. Seymour, Edward E. Held, Neal O. Hines, Frank G. Lowman, Paul R. Olson, and Arthur D. Welander. 1956. Survey of radioactivity in the sea near Bikini and Eniwetok Atolls June 11–21, 1956. Univ. Wash., Applied Fish. Lab. Rep. No. UWFL-46. 39 pp.

Goldberg, Eward D. 1952. Iron assimilation by marine diatoms. Biol. Bull., **102:** 243–248.

Goldschmidt, V. M. 1937. The principles and distribution of chemical elements in minerals and rocks. J. Chem. Soc. **655.**

Greendale, A. E., and N. E. Ballou. 1954. Physical state of fission product elements following their vaporization in distilled water and sea water. U. S. Naval Radiological Defense Lab., San Francisco 24, Cal., Technical Objective AW. 7. 24 pp.

Harvey, H. W. 1937. The supply of iron to diatoms. J. Mar. Biol. Ass. U. K., **22:** 205–219.

Krumholz, Louis A. 1956. Observations on the fish population of a lake contaminated by radioactive wastes. Bull. Amer. Mus. Nat. Hist., **110:** 281–367.

Kurbatov, J. D., and M. L. Pool. 1944. Isolation of pure radioactive cerium. Phys Rev., **65:** 61.

Larson, K. H., J. H. Olafson, J. W. Neel, an A. J. Steen. 1953. The uptake of radio active fission products by radishes and *Ladin* clover from soil contaminated by actual sub surface detonation fall-out materials. Univ Cal. (Los Angeles) Environmental Radiatio Division Rep. No. 272. 35 pp.

Miyake, Y., and Y. Sugiura. 1955. The radio chemical analysis of radionuclides in se water collected near Bikini Atoll. Paper in Meteorology and Geophysics, **6:** 33–37.

Neel, J. W., J. H. Olafson, A. J. Steel, B. F Gilloogy, Hideo Nishita, and K. H. Larson 1953. Soil-plant interrelationships with re spect to the uptake of fission products: I The uptake of Sr^{90}, Ru^{106}, Ce^{144} and Y^{91} Univ. of Cal. (Los Angeles) Environmenta Radiation Division Rep. No. 247. 44 pp.

Rice, Theodore R. 1953. Phosphorus exchang in marine phytoplankon. Fishery Bull. 80, Fishery Bull. U. S. Fish and Wildlife Serv. **54:** 77–89.

———. 1956. The accumulation and exchang of strontium by marine planktonic algae Limnol. Oceanogr., **1:** 123–138.

Schweitzer, George K., and Morrison Jackson 1952. Radiocolloids. J. Chem. Educ., **29** 513–522.

Seymour, Allyn H., Edward E. Held, Frank G. Lowman, John R. Donaldson, and Dorothy J. South. 1957. Survey of radio activity in the sea and in pelagic marine life west of the Marshall Islands, September 1–20, 1956. Univ. Wash., Applied Fish Lab. Rep. No. UWFL-47. 57 pp.

Steel, E. W., and Earnest F. Gloyna. 1955 Concentration of radioactivity in oxidation ponds. Sewage and Industrial Wastes, **27** 941–956.

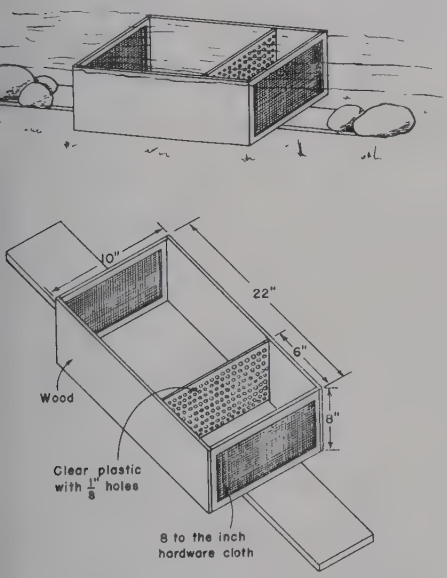
U. S. Atomic Energy Commission. 1956 Operation Troll. U. S. Atomic Energy Commission, New York Operations Office NYO4656, ed. by J. H. Harley. 37 pp.

Weiss, H. V., S. H. Cohn, W. H. Shipman, and J. K. Gong. 1956. Residual contamination of plants, animals, soil and water of the Marshall Islands two years following Operation Castle Fallout. Research and Development Report USNRDL-455NS081-001. 52 pp.

A DEVICE FOR SEPARATING SALMON FRY OF UNEQUAL SIZE

Introduction

th the sharp decline of southeastern Alaska pink
on (*Oncorhynchus gorbuscha*) runs, the U. S. Fish
Wildlife Service broadened its research program in
to include an intensive study of the ocean life of this
es. A part of this program included the marking,
n-clipping, of several thousands of pink salmon fry
lly. Their return, some 14 months later as marked
, provided a means of assessing ocean mortality.
e authors are indebted to Virginia Coleman, illus-
for the Fish and Wildlife Service at Seattle, for
e 1.



. 1. Fry-separating device of the type used.

Methods

A problem confronting the investigators during trapping of the pink salmon fry was the concurrent heavy migration of chum salmon fry (*O. keta*). Since the fry of this species were only slightly larger than those of the pink salmon, marking speed was materially reduced when the 2 remained mixed through the fin-clipping process.

It was reasoned that the natural disparity in size between the two species might allow the fry to separate themselves. Theoretically, mixed fry could be introduced within a device containing openings through which only the pink salmon could escape. After a period of trial and error, a wooden box 10 inches wide, 8 inches deep, and 22 inches long was constructed (Figure 1). The top and both ends were open, with the latter covered by 8-mesh hardware cloth. In use, the device was placed in shallow water, allowing the current to flow through its long axis and causing the fish to orient themselves toward the upper end. Rocks, piled on a "foot" protruding from the bottom at either end, held the box securely in position. A clear plastic partition 3/16-inch thick, through which 200-300 holes 1/8 inch in diameter had been drilled, was inserted 6 inches from the downstream end. Approximately 1,500 mixed fry were then introduced into the downstream or smaller compartment.

Results

Over 100 pink salmon fry per minute escaped through the partition into the upstream or larger compartment, where they needed only to be removed for marking. Only the very small chum salmon fry escaped. By actual count, the separating device proved nearly 90 per cent efficient in removing the pink salmon fry. It was noted that the more crowded the mixed fry were, the greater the escapement rate.

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A DEVICE FOR SEPARATING SALMON FRY OF UNEQUAL SIZE

By

Alton Y. Roppel and Charles R. Weaver

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ted in U. S. A.

RROWING ACTIVITIES OF THE LAR-L LAMPREYS.—Since the appearance in 1950 Applegate's work on the sea lamprey in chigan (*U. S. Fish and Wildl. Serv., Spec. Sci. pt.; Fish, No. 55*) and the subsequent develop-nt of means to control lampreys in the Great kes, biologists have accumulated much ad-ional information on adult lampreys. Larval mpreys, however, are difficult animals to ob-ve in the field, and many facets of their be-vior are still unknown. While working with e U. S. Fish and Wildlife Service, I kept mocetes in captivity, and was able to observe eir burrowing activities.

Normally, an ammocete released in water over mud bottom swims rapidly downward until hits the substratum, head down, with its body a vertical position. A continuation of this imming action pushes the anterior end of the dy into the soft bottom material an inch or ore. At this point, the swimming action stops, d the body of the larva lies over on the sur-ce of the mud. From this position it disappears oothly down out of sight into the bottom aterial without any further undulation or ticeable muscular activity. My curiosity as to w the larval lamprey accomplished this move-nt was finally satisfied after I observed the llowing procedure:

When I was holding larvae in captivity as pre-ously described (Sawyer, *Copeia, 1957(3):244*), transferred some to gallon jars. Because am-ocetes exhausted themselves trying to burrow to the bottom of the containers, a wad of tton was provided as a substratum. This emed to be a satisfactory substitute for mud, d the dark-colored animals were easily ob-rved against the white background. When re-ased in these containers, which held about 3 ers of water, the larvae swam rapidly to the ttom, began their side to side whip-like move-ents which forced their anterior ends into the cotton about an inch. Then this movement

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stopped, and the oral hood began to function. The ammocete warped its hood to one side or the other, and cast about rapidly, selecting the best route through the apertures in the cotton. At times, the mobile, lip-like structure was flared out at an advantageous point to serve as an anchor against which muscular contraction pulled. The flexibility of the oral hood was very great. It was folded in from side to side to make a sharp point which could be inserted through a tiny hole, or it was flared out to the right or left to serve as an anchor much in the same manner as the foot of a bivalve. Simultaneously, it appeared that the larvae used the loops of their bodies to push against their substratum similarly to the horizontal undulatory movements of a snake (Schmidt and Davis, *Field Book of Snakes of the United States and Canada, p. 47*, 1941). As the oral hood constantly sought the most easily traversed route through the cotton and held when necessary or continued to probe, the myomeric muscles of the trunk pushed against the irregularities of the cotton. Thus the tail end of the ammocete was gradually and smoothly drawn into the bottom material. Wriggling activity continued until the animal was well embedded within the cotton. At this point most forward progress stopped. The oral hood, however, often continued its movements and from time to time the whole body was advanced a little. The ammocete remained in this position for some time, appearing to rest after the strenuous burrowing activity. Larvae always preferred to be within the cotton, rather than just under it. Even when feeble as a result of treatment with chemicals they attempted to re-enter the substratum if they had wriggled out of it.—Philip J. Sawyer, *Department of Zoology, University of New Hampshire, Durham, New Hampshire.*

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New Records Of Gulf Of Maine Fishes

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The following notes concern captures of unusual Gulf of Maine fish.

Carcharodon carcharias (Linnaeus); Great white shark or "maneater." In the files of the Portland Society of Natural History are detailed measurements of a 11-foot, 11-inch white shark caught in a haddock gill net by Captain Frank Doggett of the *Hortense*, October 10, 1931. The net was set in 25 fathoms of water on Bulwark Shoal, off Portland, Maine. Identification and measurements were by W. H. Rich of the U. S. Bureau of Fisheries and A. H. Norton of the PSNH. The October 10, 1931 Portland Evening Express described this shark as 15 feet long and 1,500 pounds, both exaggerations.

Cetorhinus maximus (Gunnerus); Basking shark. On July 27, 1954, an immature 11-foot, 6-inch basking shark was caught in Eugene Rackliff's herring weir at Wheelers Bay, Knox County. This fish had the bottle-nosed snout characteristic of the young.

This species can no longer be considered as uncommon along the Maine coast. Sportsfishermen operating out of Boothbay Harbor report that in recent years large basking sharks are often sighted, but seldom harpooned because of the difficulties in handling such large fish. They are also ignored by commercial fishermen, for these sharks have no market value. Those wandering into herring weirs are removed without fanfare, and we seldom learn of such captures.

Anchoa hepsetus (Linnaeus); Striped anchovy. The striped anchovy has been reported only once in Maine — near Portland in October 1930 (Kendall, 1931, Boston Soc. Nat. Hist. Bull. 58: 9-11). In 1958, these fish were caught in Lincoln County, Maine on several occasions. On October 15, a 5¼-inch specimen was found with sardine-sized herring (*Clupea harengus*) caught in Alden Swett's stop seine in Sheepscot Bay near Isle of Springs. Two days later, two more striped anchovies (5 and 5¼ inches long) were caught

in John Swett's herring stop seine near Capitol Island. On October 27, Douglas Anderson of Port Clyde Packing Company found two 5-inch specimens in a load of sardine herring from a stop seine at Ram Island. A week later, he saw several more in a catch of sardine herring from Damariscove Island.

On October 29, five more (4¾, 5, 5¼, 5¼, and 5¾ inches long) of this species were seen in a small sample of sea herring (*C. harengus*) and round herring (*Etrumeus sadina*) caught in a Provincetown, Massachusetts, pound net. Since the sample was only a tiny part of the pound net landings at Provincetown that day, many thousands of anchovies must have been caught.

Paralichthys dentatus (Linnaeus); Summer flounder. Robert McClellan of Boothbay Harbor caught a 15½-inch male summer flounder while otter-trawling for grey sole April 24, 1958, eight miles SW of Monhegan Island, Maine. The testes were well developed. Only one other Maine record of this species exists (Scattergood, 1953, Copeia, 1953 (3): 195).

Nemichthys scolopaceus Richardson; Snipe eel. The Gloucester, Massachusetts otter trawler *Vincie N.* caught a 24½-inch snipe eel near Cashes Ledge (42° 47′ N. and 69° 29′ W.) on May 14, 1957. The specimen was given to Claude Bocken of the Bureau of Commercial Fisheries in Gloucester. This is the second record of this fish in the Gulf of Maine. The other was found in the stomach of a codfish caught on Georges Bank in 1879 (Goode and Bean, 1895, Smithsonian Contrib. Knowl., vol. 30, p. 152).

Paralichthys oblongus (Mitchill); Four-spotted flounder. A 14-inch specimen was caught August 4, 1958 by Robert McClellan while fishing for whiting in 11 fathoms of water off Griffiths Head, Sagadahoc County, Maine. There is only one other Maine record (Scattergood, 1958, Maine Field Nat., *14* (2): 41) of this fish that is common in southern New England.

Decapterus macarellus (Cuvier and Valenciennes); Mackerel scad. Two more of these fish were caught in Lincoln County, Maine during 1958. There have been only four other records of this species in Maine (Scattergood, 1958, *op. cit.*). On August 14, Douglas Anderson found a 7¾-inch female with full ovaries in a load of sardine herring caught by stop-seiner Henry Jones at Fisherman's Island. Ted Farrin caught a 4-inch specimen in his Pemaquid Point fish trap during the first week of September.

Naucrates ductor (Linnaeus); Pilot fish. This species is a tropical fish of the high seas (Bigelow and Schroeder, 1953, U. S.

Fish Wildl. Serv., Fish. Bull. 75: 373) and is rarely caught in Maine waters. Three more records have been found recently.

In the files of the PSNH, there is a sketch and identification by W. H. Rich of a 7½-inch pilot fish caught July 31, 1929 at Richmond Island, Cumberland County.

There are two other records that are unusual because the fish were caught while swimming near the leatherback turtle *Dermochelys coriacea* instead of accompanying sharks, with whom they are usually found. A 10½-inch specimen was speared by Willis Brewer of Southport, Maine, who had harpooned a leatherback turtle five miles SE of Sequin, Island, Sagadahoc County, August 25, 1937. The fish was one of several swimming around the turtle and was identified by personnel at the Boothbay Harbor fisheries station. Whiteley 1938 (Copeia, 1938 (2): 94) described the captures of both the turtle and fish, but was unable to identify the latter. Christopher Packard of the PSNH has told me that he saw a small school of pilot fish swimming alongside a leatherback turtle that was towed to Harpswell after being harpooned off Lumbo Buoy, Casco Bay, Cumberland County, August 29, 1958. Packard caught and identified one of the fish.

Balistes carolinensis Gmelin; Trigger-fish. The PSNH files have a sketch of a 16⅛-inch trigger-fish caught in a fish trap at Pond Island Ledge, Casco Bay, Cumberland County, on August 10, 1931. The fish was identified by W. H. Rich and A. H. Norton. Only two specimens of this tropical fish have reported from Maine (Scattergood, Trefethen, and Coffin, 1951, Copeia, 1951 (4): 298).

Spawning Of North American Herring

LESLIE W. SCATTERGOOD, CARL J. SINDERMANN, AND BERNARD E. SKUD

U. S. Department of the Interior, Bureau of Commercial Fisheries Fish and Wildlife Service, Boothbay Harbor, Maine

ABSTRACT

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ABSTRACT

The spawning of the North American herring on the Atlantic and Pacific coasts is compared. Spawning occurs somewhere on the North American continent during every month of the year. The spawning time progression on the Pacific coast is from mid-winter in the southern part of the range to early summer in the northern part. The Atlantic coast spawning has two peaks — spring and autumn; spring activities dominate in the northern part and autumn in the south. The range of spring-spawning temperatures on both coasts is comparable. While the major portion of spawning on the Atlantic coast takes place on rocky or gravel bottoms, the eggs of Pacific herring are most often attached to marine vegetation.

INTRODUCTION

The range of herring in North America extends generally north of 32° north latitude. *Clupea harengus* on the Atlantic coast is found as far south as Cape Hatteras and north to northern Labrador (Bigelow and Schroeder, 1953). Its Pacific counterpart, *Clupea pallasi*, ranges from near San Diego to the Arctic regions of northern Alaska. Recent studies in the Arctic by Wilimovsky (1954), Walters (1955) and J. G. Hunter of the Fisheries Research Board of Canada (correspondence) have verified early records that the distribution reaches at least to Cape Bathurst in the Beaufort Sea (Figure 1).

The ranges of the herring are great, yet these fish are abundant enough to be of considerable economic interest only in the centers of their range between Western Alaska and British Columbia, and Newfoundland and Maine. In those areas, the herring fisheries are pursued vigorously. With the exception of the fisheries for immature herring that are used for sardines in Maine and New Brunswick, the principal effort is devoted to capturing mature herring.

Herring deposit their sticky, demersal eggs somewhere in North American waters during every month of the year. The spawning seasons are usually referred to as spring and autumn. There is, of course, some spawning in summer and winter; the principal periods of egg laying, however, occur in spring and autumn. Spring spawning is defined here as January through July; and autumn spawning, August through December. This is recognized as a somewhat artificial division.

It is well to make the distinction between the two terms: (1) spring- or autumn-*spawning* fish and (2) spring- or autumn-*spawned* fish. In an area where both spring- and autumn-spawning activities occur, individuals spawning in one season may themselves have been spawned in another season. Thus an autumn-spawned herring may, upon reaching maturity, become either an autumn-spawning or a spring-spawning fish (Jean, 1956).

LOCATIONS AND TIMES OF SPAWNING

Pacific Coast

A northerly and westerly progression in spawning time along the Pacific coast from California to the Bering Sea was pointed out by Rounsefell (1930). Exceptions to this progression occur in local areas, but the general pattern holds for broad geographical areas (Skud ms.).

California. In the San Diego region, spawning may begin in mid- or late December, which is a month earlier than for more northerly parts of the California coast (Miller and Schmidtke, 1956). No large numbers of herring have been observed in the vicinity of San Diego, which may possibly represent the southern breeding grounds of this species. In the two principal California spawning areas, San Francisco and Tomales Bays, eggs may be deposited as late as March, but most of the spawning occurs in January and February.

Oregon. Information on Oregon herring is not extensive, because the species is of minor importance there. The principal spawning areas

FIGURE 1.—Distribution of North American herrings; *Clupea harengus* in Atlantic Ocean and *C. pallasi* Pacific Ocean.

n the Oregon coast are Yaquina, Tillamook, nd Coos Bays. Cleaver (1951) mentions that pawning herring visit those bays in the late inter months. According to Westrheim (peronal communication of October 2, 1958), pawning occurs in Yaquina Bay from January 5 April and in Tillamook Bay from February 5 April.

Washington. In Washington waters, spawng has been reported from late December to arly or middle May (Chapman, Katz, and Erickson, 1941). December spawning occurred on only one of the known grounds; in the Puget Sound region the major part of the spawning was during February and March. Spawning at any particular locality was usually completed within two weeks.

British Columbia. In recent years, more herring have been caught in the province of British Columbia than in all the other Pacific coast states and Alaska, combined. The catch data, coupled with the extensive spawning observed each year, indicate that this area is probably the center of abundance for the species on the Pacific coast of North America. The heaviest spawning occurs in the southern waters of the lower east coast of Vancouver Island. In southern British Columbia, Tester (1935) reported that spawning began during the latter part of February; in northern waters near the Alaskan border it began in the early part of March and ended in the last of April. More recently, Outram (1955) reported a spawning as late

as July 2 - 3 in Burke Channel in northern British Columbia.

Southeastern Alaska. On southeastern Alaskan beaches where spawning occurred each year, Skud (ms.) found that there was less variation in time of spawning than for areas where spawning did not occur annually. Spawning seldom started before mid-March, and all major activity was completed by the end of May. The heaviest concentration of egg depositions, which were generally located in the vicinity of Sitka, occurred in late March and early April. Occasional spawnings have been reported as late as June in other areas of southeastern Alaska, but they have never been as extensive as the earlier spawnings.

Central and Western Alaska. Rounsefell (1930) stated that spawning took place in April and May in Prince William Sound and Cook Inlet on the central Alaska coast. Farther west and north in the Kodiak-Afognak area, herring spawned in May and June. The most northerly record of spawning is in the Bering Sea near St. Michaels, Alaska, during the month of June (Nelson, 1887).

Atlantic Coast

The determination of spawning times and areas of the Atlantic coast herring is more difficult than for the Pacific species. Differences in spawning habits are responsible for this. The Pacific coast herring spawn in the intertidal zone, and the principal spawning areas are therefore readily observed. On the Atlantic coast, intertidal spawning has been reported only occasionally from Newfoundland (Tibbo, 1956). Egg laying generally occurs on bottoms too deep for the egg masses to be visible. Fortunately, where there are well organized herring fisheries for the mature fish, such as in Quebec and the Canadian maritime provinces, the spawning times and locations may be deduced from the condition of the gonads. Along the United States coast, however, no regular large-herring fishery exists, and, consequently, frequent samples of mature fish are not easy to obtain. However, plankton surveys for herring larvae do provide information concerning where and when spawning occurs. Such surveys have been carried on during the past few years in the Gulf of Maine by the joint efforts of biologists of the Fisheries Research Board of Canada and the Fish and Wildlife Service (Tibbo, Legare, Scattergood and Temple, in press).

Middle Atlantic Region. South of New England, herring are not abundant. Annual catches of a few million pounds are often made during the winter in New York and New Jersey, but only minor quantities are taken from Delaware south to Virginia. From the condition of the gonads of New Jersey and Maryland samples, the fish appear to be autumn spawners. Young larval herring were reported by Perlmutter (1939) from southwest Long Island, New York in October, indicating that there had been autumn spawning.

Southern New England. Block Island Sound, off the coasts of Connecticut and Rhode Island, has a winter fishery for spent herrings (Sanders, 1952). Merriman and Sclar (1952) reported the capture of small larval herring there in the autumn, but Wheatland (1956) showed that those fish were menhaden. Moore (1898) believed that spawning occurred during November in Block Island Sound and during October and November in southern Massachusetts at Vineyard Sound. There is no evidence of spring spawning in Southern New England.

Northern New England. In the Gulf of Maine, along the shores of Massachusetts and Maine, there have been many areas on which herring have spawned in the past (Bigelow and Schroeder, 1953). At the present time, according to the results of experimental fishing and larval herring surveys, it seems that spawning is no longer so widespread. Now, the greatest concentrations of spawning fish in eastern United States waters appear to be on Georges Bank, about 100 miles east of Cape Cod. We do not know how important Georges Bank has been as a spawning ground in the past or whether the decrease in spawners along the New England coast has been accompanied by an increase on Georges Bank. Spawning in the Gulf of Maine and on the Maine coast occurs principally in September and October (Scattergood, 1952).

Canada. In Canada the spawning times and localities are better known than in the eastern United States. Some fish have been reported as spawning in April and May in the Bay of Fundy, making that area the southernmost limit of spring spawners. From Halifax south to Yarmouth and including the Bay of Fundy, spawning is mainly in late August and September (Leim, 1957). Along the outer coast of Nova Scotia east of Halifax, there are two spawning seasons, a major one in May or early June and a minor one in September. This con-

ion prevails in the Gulf of St. Lawrence, ex-
ot that along the south and west coasts of
ewfoundland the May and June spawning
y be the only one. Some spawning may oc-
over a period from April to September, as
n (1956) has reported for the Bay of
aleur, Quebec.

It seems evident that the spawnings of the
lantic coast are more complex than those of
e Pacific. There are multiple spawning sea-
ns within an area and almost continuous
awning for as long as six months in certain
eas. The striking fact, however, is that while
e Pacific coast has spring spawning, the
lantic has both spring and autumn, with
e autumn activities dominant in the southern
rt of the range and the spring being most
portant in the north. Among autumn
awners, there is some southward progression
spawning time — from late August in Nova
otia to October in southern New England.

TEMPERATURE AT SPAWNING

The temperature during spawning on the
cific coast ranges from 3.0° to 12.3° C and
similar to the range of Atlantic coast spring
awnings, 2.2° - 12.4° C, whereas, Atlantic
l spawnings occur at generally higher tem-
ratures, 7.7° - 15.0° (Table 1). Surface
mperatures are representative of spawning
mperatures when fish spawn in shallow in-
ore waters, whereas, the water temperature in
ep spawning areas varies widely from surface
mperatures during certain seasons of the
ar. However, in autumn spawnings, such as
ose on Georges Bank, the differences at the
rface and to depths of at least 100 feet are
nerally small because of the turbulent mixing
the waters.

TYPES OF SUBSTRATE

Bigelow and Schroeder (1953) reported that Atlantic herring spawn chiefly on rocky, pebbly, or gravelly bottoms, on clay to some extent, probably never on soft mud. They also noted that eggs were occasionally found sticking to anchor ropes of fishing vessels. Moore's (1898) observations of Grand Manan, N. B. confirmed these reports and added shells as an important substrate. These findings were in general agreement with Hodgson's (1957) descriptions of areas utilized for spawning in European waters.

In contrast, Pacific herring eggs are most often attached to various types of marine vegetation. Several authors, Hart and Tester (1934), and Chapman, Katz, and Erickson (1941), and others indicated that eel grass (*Zostera*) and rockweed (*Fucus*) were the preferred vegetation. Extension spawning on other seaweed such as vine kelp (*Macrocystis*) and bladder kelp (*Nereocystis*) was noted by Skud (ms.).

It is difficult to say whether or not these substrate differences between Atlantic and Pacific herring are merely associated with the depths and locations of spawning or whether the fishes of either coast actively seek out a particular substrate.

LITERATURE CITED

BIGELOW, HENRY B., AND WILLIAM C. SCHROEDER. 1953. Fishes of the Gulf of Maine. U. S. Dept. Int., Fish Wildl. Serv. Bull., Vol. 53, viii + 577 pp.

CHAPMAN, WILBERT M., MAX KATZ, AND DONALD W. ERICKSON. 1941. The races of herring in the State of Washington. Wash. Dept. Fish., Biol. Rept. No. 38A, 36 pp.

TABLE 1.—*Time and water temperature for spawning of North American herring*

Source	Location	Spawning time	Temperature °C
ific			
Miller (1956)	California	Jan.–Apr.	8.0–10.0
Vestrheim (communication)	Oregon	Jan.–Apr.	3.8–12.3
Outram (1955)	British Columbia	Feb.–Apr.	4.4–10.7
Skud (ms.)	Southeastern Alaska	Apr.–May	6.1–11.0
Rounsefell (1930)	Western Alaska	Apr.–May	3.0–5.5
antic			
Tibbo (1956)	Newfoundland	May–June	8.0
ean (1956)	Quebec—Bay of Chaleur	May–June	2.2–12.4
Bigelow and Schroeder (1953)	New Brunswick—Grand Manan	Aug.–Sept.	7.1–11.1
Bigelow and Schroeder (1953)	Massachusetts—Cape Cod	Oct.–Nov.	up to 12.8
Tibbo, *et al*, (In press)	Georges Bank	Sept.–Nov.	11.9–13.9

CLEAVER, FRED C. 1951. Fisheries statistics of Oregon. Oregon Fish. Comm., Contrib. No. 16, 176 pp.

HART, JOHN LAWSON, AND ALBERT L. TESTER. 1935. Quantitative studies on herring spawning. Trans. Am. Fish. Soc., Vol. 64, pp. 307-12.

HODGSON, WILLIAM C. 1957. The herring and its fishery. London, Routledge and Kegan Paul, xiii + 197 pp.

JEAN, YVES. 1956. A study of spring and fall spawning herring. (*Clupea harengus* L.) at Grande-Riviere, Bay of Chaleur, Quebec. Dept.. Fish. Quebec, Contrib. No. 49, 76 pp.

LEIM, A. H. 1957. Summary of results under the Atlantic Herring Investigation Committee. Fish. Res. Bd. Can., Bull. No. 111, pp. 1-16.

MERRIMAN, DANIEL, AND RUTH C. SCLAR. 1952. The pelagic fish eggs and larvae of Block Island Sound. Bull. Bingham Oceanogr. Coll., Vol. 13, Article 3, pp. 165-219.

MILLER, DANIEL J., AND JOHN SCHMIDTKE. 1956. Report on the distribution and abundance of Pacific herring (*Clupea pallasii*) along the coast of central and southern California. Calif. Fish and Game, Vol. 42, No. 3, pp. 163-187.

MOORE, H. F. 1898. Observations on the herring and herring fisheries of the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. U. S. Comm. Fish., Rept. of Comm. for 1896 (1898), pp. 387-442.

NELSON, EDWARD, W. 1887. Field notes on Alaskan fishes. *In* Report upon natural history collections made in Alaska between years 1877 and 1881. Washington, Gov't Printing Off., pp. 297-322.

OUTRAM, D. N. 1955. Extent of herring spawning in British Columbia waters during 1955. Fish. Res. Bd. Can., Circ. No. 37, 10 pp.

PERLMUTTER, ALFRED. 1939. A biological study of the salt waters of Long Island, 1930. Section I. An ecological survey of young fish and eggs identified from the tow net collections. Suppl. 28th Ann. Rept. N. Y. Cons. Dept., Pt. II, pp. 11-71.

ROUNSEFELL, GEORGE A. 1930. Contribution to the biology of the Pacific herring, *Clupea pallasii*, and the condition of the fishery in Alaska. Bull. U. S. Bur. Fish., Vol. 45, pp. 227-320.

SANDERS, HOWARD L. 1952. The herring (*Clupea harengus*) of Block Island Sound. Bull. Bingham Oceanogr. Coll., Vol. 13, Article 3, pp. 220-237.

SCATTERGOOD, LESLIE W. 1952. The maturity of the Maine herring (*Clupea harengus*). Maine Dept. Sea Shore Fish., Res. Bull. No. 7, 11 pp.

SKUD, BERNARD E. Ms. Herring spawning surveys in Southeastern Alaska. U. S. Fish and Wildlife Service, Alaska Herring Investigation.

TESTER, ALBERT L. 1935. The herring fishery of British Columbia — past and present. Biol. Bd. Can., Bull. 47, pp. 6-10.

TIBBO, S. N. 1956. Populations of herring (*Clupea harengus* L.) in Newfoundland waters. Jour. Fish. Res. Bd. Can., Vol. 13, No. 4, pp. 449-466.

TIBBO, S. N., J. E. HENRI LEGARE, LESLIE W. SCATTERGOOD, AND ROBERT F. TEMPLE. In press. On the occurrence and distribution of larval herring (*Clupea harengus* L.) in the Bay of Fundy and the Gulf of Maine. Jour. Fish. Res. Bd. Can.

WALTERS, VLADIMIR. 1955. Fishes of western Arctic America and eastern Arctic Siberia. Taxonomy and Zoogeography. Bull. Amer. Mus. Nat. Hist., Vol. 106, Article 5, pp. 257-368.

WHEATLAND, SARAH B. 1956. Oceanography of Long Island Sound, 1952-1954. VII. Pelagic fish eggs and larvae. Bull. Bingham Oceanogr. Coll., Vol. 15, Article 7, pp. 234-314.

WILIMOVSKY, NORMAN J. 1954. List of the fishes of Alaska. Stanford Ichthy. Bull., Vol. 4, No. 5, pp. 279-294.

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By LESLIE W. SCATTERGOOD *and* S. N. TIBBO

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W. E. RICKER
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ABSTRACT

A general account is given of the history of the Northwest Atlantic fishery for herring (*Clupea harengus* L.) from aboriginal days to the present. The average catch during the last three decades has been 142,000 metric tons annually (313 million lb). About half of the catch is made on the Maine coast and in the Bay of Fundy; the Canadian Atlantic and the Gulf of St. Lawrence regions yield almost all of the remainder. The size of the catch seldom reflects the availability of the species in the fishing areas. Expansion of the fishery depends upon increased demand accompanied by a price that will make the fishery profitable. Offshore herring stocks, yet unfished, can be harvested, and new and better types of gear can be developed to yield greater catches.

INTRODUCTION

The sea herring (*Clupea harengus* L.) is one of the most abundant and important fishes in the North Atlantic. In Europe, the largest fisheries are in the Norwegian and North Seas. The species is taken commercially as far south as the Strait of Gibraltar. There are herring fisheries in Greenland, Iceland, and in the Arctic Ocean as far east as Siberia. In North America, herring are caught on the Atlantic shores from Labrador to Virginia; the principal fisheries are north of Cape Cod. In the western Atlantic, most of the herring are caught along the coasts; there are no offshore fisheries comparable to those of Europe.

In general, the North American herring fisheries are a series of localized operations of interest primarily to local fishermen and processors; however, in one important area, the fishery is of mutual concern to both Canada and the United

FIG. 1. Map of area showing provinces and states and principal localities mentioned.

States. Here, in a large region that includes the coasts of southern New Brunswick and all of Maine, the Canadian and United States processors of canned immature herring often depend upon a common supply of small herring or "sardines". Because of this joint interest in the availability of fish, scientists of the Fisheries Research Board of Canada and the United States Fish and Wildlife Service are cooperating to an increasing extent in biological studies of the herring in order to provide information that will be of value in utilizing the species to the best advantage.

The purpose of this paper is to offer a brief review of the herring fishery on the eastern shores of North America with particular reference to its present status. No such general summary has been made previously, and, consequently, few people in Canada and the United States have been familiar with the extent and utilization of the herring resources in both countries.

HISTORY OF THE FISHERY

Herring fisheries were well established in Europe many centuries before the discovery of America. Samuel (1918) has summarized the existing knowledge of their early development. Some have believed that herring fishing began at Yarmouth, England about 495 A.D. One of the earliest references is from the Evisham monastery chronicle in which the English herring fishery of the year 709 A.D. was mentioned. Another record indicates that in 836 A.D., the Dutch went to Scotland to buy salted fish -presumably herring. There are frequent references to Norwegian herring fisheries in the Icelandic sagas of the latter part of the tenth century, and there are records of a French herring fishery in the early eleventh century. It is apparent from these historical accounts that the early fishermen and colonists in North America may have been quite familiar with the methods of capturing and preserving herring.

The history of the herring fishery in the eastern parts of Canada and the United States is not as well documented as that in Europe. Not a great deal is known of the aboriginal fisheries prior to the visits of European fishermen about 450 years ago. The Indians had weirs, and herring as well as other shore fishes were probably taken in these rather simple forms of stationary gear

FIG. 2. Torching for herring at night in Ipswich Bay, Mass. (From sketch by J. S. Ryder about 1880.)

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(Earll, 1887). "Torching" (in some regions called "driving"), was also used by the aborigines, for this night method of fishing requires only a moving boat, a flaming torch to attract the herring to the water's surface, and a dip-net to capture the fish.

Fortunately, much information on the early history of the western Atlantic herring fishery can be inferred through the study of the somewhat better documented cod fishery, because herring was one of the principal baits for the long-lines and handlines that were used during the early cod fishery in Canada and the United States (Innis, 1954). As the North American fishery for cod developed, so did that for herring, because the Europeans found that at certain seasons herring suitable for bait could be caught in great numbers in the western Atlantic. Vessels fishing on the banks took many herring with gill nets set at night from the stern. Smith (1833) states that the first knowledge we have of the North American fisheries was in 1504 when the Newfoundland area was visited by French cod-fishing vessels. Portuguese and Spanish ships soon joined the fishing fleets, and by the middle of the sixteenth century the English were also sending fishing vessels to the eastern shores of the New World.

The eastern North American herring fishery, although never attaining the importance of that in Europe, played a definite role in the early economy of the coast areas of New England and the Maritime Provinces. During the seventeenth century, the French and English intensified their colonization of what is now Eastern Canada and the United States, and increasing amounts of herring were used as food. The colonists also entered the cod fisheries, and a thriving salt cod export trade was established. This greater cod-fishing activity undoubtedly increased the use of herring as bait.

FIG. 3. A modern New Brunswick "sardine" cannery. (Photograph by P. W. G. McMullon, courtesy Connor's Bros. Limited, Black's Harbour, N.B.)

Herring were evidently plentiful in the early colonial days, for, speaking of these fish, Captain John Smith (1624) said ". . . the Saluages [savages] compare the store in the Sea with the haires of their heads; and surely there are an incredible abundance upon this coast". Josselyn (1675) reported that, during his visit in New England in 1670, herring were numerous and were taken all summer long. However, historical accounts of the fisheries, such as those by Josselyn (1675) and Sabine (1853), do not always make clear distinctions between the river herrings or alewives (*Pomolobus pseudoharengus* and *P. aestivalis*) and the sea herring (*Clupea harengus*).

FIG. 4. The interior of a Maine sardine cannery.
Top left: Removing sardines from the cookers.
Top right: Cutting and packing the fish.
Bottom left: A conveyor belt from the packers to sealing machine.
Bottom right: A sealing machine.

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Before the end of the eighteenth century, United States fishing vessels had expanded their operating range from New England northward to the Canadian coasts. These vessels were engaged in the cod fishery on the Grand Bank of Newfoundland and later began operating in the Gulf of St. Lawrence and along the Labrador coast (Earll, 1887). Herring were caught for bait near the cod grounds.

During the early part of the nineteenth century, the demand for herring exceeded the supply available in United States waters, and New England vessels began buying herring at the Magdalen Islands, in the Gulf of St. Lawrence. These fish were salted or pickled and transported to Maine or Massachusetts where they were used for bait or reprocessed for food. During the 1850's, frozen herring were purchased in Newfoundland and brought to the United States to be used as bait for groundfishing. Later frozen herring were obtained from New Brunswick and Nova Scotia. By the latter part of the nineteenth century, the markets for salt herring had declined, and during the early years of the twentieth century, the groundfish longlining and handlining methods were being replaced by otter trawling, thus reducing the amounts of herring needed for bait. By the beginning of the twentieth century, few United States vessels were engaged in the salted, pickled, or frozen herring trade with Canada. Canadians still caught, preserved, and exported these fish, but to a declining market.

Two historically recent developments in the fisheries have led to an increased use of herring. One was the canning of young herring as sardines. This industry began in eastern Maine in the 1870's and later spread to neighbouring New Brunswick and along the entire Maine coast. Prior to this sardine fishery, the small herring or sardines were used only for oil and fertilizer, and the larger herring were smoked. To-day the sardine-canning industry purchases the great bulk of the herring taken in the United States and southern New Brunswick. The other development was the expansion and intensification of lobster fishing in both countries after the 1860's (Found, 1912). This fishery has been carried on with great vigor, and large quantities of herring are used as bait, particularly in eastern Maine and the Canadian Maritime Provinces.

QUANTITIES LANDED

Although the herring fishery of eastern North America is more than four centuries old, comprehensive information on the total landings of herring in the eastern United States and Canada is available for only a relatively short period of time. Prior to World War I, the fishery statistics were not collected regularly. After the war, there was a great improvement in the frequency and coverage of the statistical surveys; consequently, the years from 1920 to 1954 have been selected to show the magnitude and trends of the herring fisheries.

From 1867, the time of Confederation in Canada to the end of 1910, Canadian fisheries statistics were collected on an annual basis by fisheries field personnel (officers of the Fisheries Branch of the Department of Marine and Fisheries). The statistics collected were not as extensive as those collected today, and dealt mainly with the quantity and value of the yearly catch, the quantity and value of fish exports, and a few other yearly series. Except for statistics of fish exports, which had a basis in recorded transactions, the system of statistical collection was quite elementary, and the estimates of fish landings were likely of dubious authenticity for some or many sections of the Maritime Provinces.

In 1911, the collection of statistics of fish landings on a monthly basis was introduced, and while the Fisheries Branch was transferred from the administration of the Department of Marine and Fisheries to that of the Naval Service for a period of six years (July, 1914-July, 1920), and a separate Department of Fisheries was formed in 1930, the procedures and methods employed in the collection of statistics underwent no major change until 1956. Improvements in the type of statistical forms employed and in the detail of statistics gathered did take place; but basically, the method of collecting data on fish catches remained the same—officers compiled their monthly statements of quantities of fish landed on the basis of estimates obtained from fishermen, fish buyers and fish processors.

While the method of collecting statistics during the period 1911-1956 remained substantially unchanged, the departmental reorganization of 1947 served to improve the quality of the primary statistics. This reorganization involved the setting up of Protection and Inspection Services within the Department, and the responsibility for the collection of statistics was placed upon the personnel of the Protection Service. This meant that a larger number of officers, whose work duties required more frequent visits to fishing ports, were charged with the collection of statistics, thereby facilitating and improving statistical field work.

In the southern New Brunswick region, where small herring are caught to be canned as sardines both in the United States and Canada, much reliance is placed on the purchase records of the Canadian canneries and on the export statistics of the Canadian Customs service. The statistics are submitted to the Department of Fisheries regional offices and are compiled annually by the Dominion Bureau of Statistics.

The United States was unable, because of limited appropriations, to establish complete and regular statistical coverage of its Atlantic coast fisheries before 1929. For the five-year period 1929 to 1933, the data are complete, but interruptions occurred thereafter. Information for the years 1934, 1936, 1941, 1943 and 1946 is not available, but after 1947 censuses have been completed for each year.

The United States has had various methods for collecting information on the herring catches. Up to 1939, statistical agents of the United States Bureau of Fisheries gathered the data on fish production, including herring, in the various states. These men travelled along the coasts and asked the fishermen the poundage and value of the fish caught and the types and quantities of

gear used in the preceding year. A complete canvass of the fishery industry of a state the size of Maine required about one-man-year of effort; consequently, annual production figures were usually available one or more years late.

Since 1939, the fishery statistical systems of the herring-producing states on the east coast of the United States have been gradually changing from a purely federal undertaking to either state or joint federal–state operations. The Maine Department of Sea and Shore Fisheries, under the guidance of the United States Bureau of Fisheries, began collecting monthly catch figures in 1939. These monthly canvasses were the sole responsibility of the state until 1946 when the United States Fish and Wildlife Service (successor to the Bureau of Fisheries) began to share the task. This cooperative endeavour has continued. Such joint arrangements have also been established between the Fish and Wildlife Service and the states of Rhode Island, New York and New Jersey. The state of Maryland collects monthly figures independently. Statistics from New Hampshire, Massachusetts, Connecticut, Delaware and Virginia are still the responsibility of the federal government, with state personnel assisting at times.

Maine is the most important herring-producing state, and considerable effort has been expended to improve its statistical system. When the Maine Department of Sea and Shore Fisheries began collecting monthly fisheries statistics, its wardens were given the responsibility for obtaining the information concerning herring landings. Each warden was expected to interview the fishermen in his district each month to learn how many pounds of herring had been caught. This system did not provide the daily catch records nor the exact localities of capture—both types of information that are valuable in understanding the movements and availability of herring.

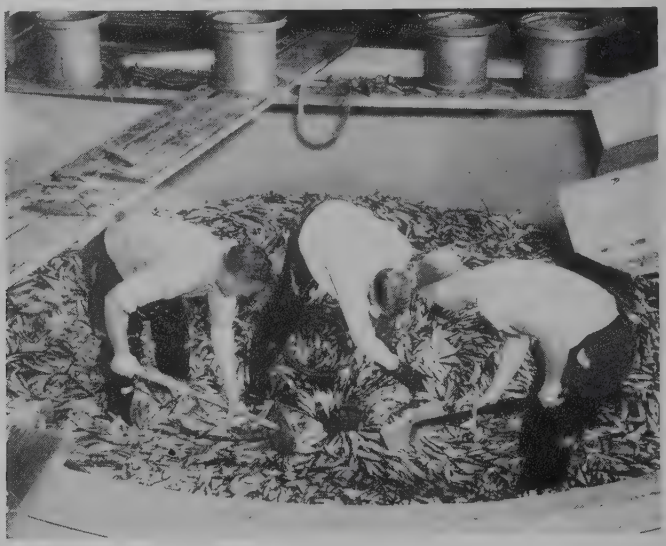

FIG. 5. State of Maine Inspectors examine load of sardines before delivery to the canneries. (Photograph by Richard Merrill.)

In 1947, the Maine Sardine Packers Association, the Maine Department of Sea and Shore Fisheries and the Fish and Wildlife Service began a cooperative herring investigation, under the direction of the federal agency. Improvement of herring catch records was an important part of the study (Scattergood, 1949; Scattergood and Trefethen, 1952). In 1947, scientific personnel of this investigation, with the assistance of the sardine cannery operators, were able

to obtain daily catch records of herring landed at the canneries. Each landing record had the fisherman's name, quantity of herring caught, date and locality of capture, and the name of the cannery. Similar data were collected from fish meal plants, herring smokers, herring picklers, and cat food canners. This system was a great improvement over the previous arrangement that depended entirely upon warden's reports. In 1948, the wardens were no longer charged with the responsibility for the herring statistics; instead, the herring investigation staff and the Maine statistical agents, both state and federal, obtained the data directly from the purchasers, as in 1947.

In 1949 a further change occurred. The Maine Department of Agriculture agreed to have its Division of Inspection personnel, stationed at each sardine cannery, provide the necessary landing information on Keysort cards. The inspectors forward the cards to their central office where they are examined by the statistical agents of the Fish and Wildlife Service and the Maine Department of Sea and Shore Fisheries. These agents use the information in their monthly Maine fish landing reports. The cards are then given to the scientific personnel of the Fish and Wildlife Service's Atlantic Herring Investigations.

Table I shows the landings of herring in the Northwest Atlantic region between 1920 and 1954. The United States production is shown by states from Virginia to Maine. Canada's landings are divided into five principal regions rather than by provinces. The Bay of Fundy region includes parts of both New Brunswick and Nova Scotia, and has a shoreline from the international boundary in southern New Brunswick to Digby County, Nova Scotia. The Atlantic coast area extends from Yarmouth County to Victoria County, all in Nova Scotia. The Southern Gulf region extends from Inverness County, Nova Scotia, to Restigouche County, New Brunswick, and includes the Magdalen Islands and Prince Edward Island. The Northern Gulf area includes the Gaspé peninsula, Anticosti, and the north shore of the Gulf of St. Lawrence from Orleans Island to the Strait of Belle Isle. The Newfoundland and Labrador region includes the waters around those two geographical areas.

The fisheries of two adjacent regions, the state of Maine and the Canadian Bay of Fundy, produce almost half of the total herring landed from Northwest Atlantic waters. Herring production in the other parts of the eastern United States is of minor importance; the remaining Canadian Atlantic regions, however are large producers. The average yearly Atlantic herring catches during the periods for which we have records are 43,916 metric tons[1] for the United States and 98,344 metric tons for Canada. The maximum yield in the United States was 89,142 tons in 1950, and in Canada 187,633 tons in 1946. The 242,311-ton total catch in 1948 is the maximum for the two countries together.

Figure 6 shows the landings as compiled in Table I and includes totals for the years 1924, 1928, 1941, 1943 and 1946. Some of the landings were not reported (Table I) for these years but are likely to affect the overall totals only very slightly. The yearly Canadian herring catches began rising with the beginning of the Second World War in 1939 and then decreased after 1946. The post-war catches, however, have not declined to the level of the pre-war production. In comparison to those of Canada, the United States catches show much greater fluctuations from year to year. Maine is the greatest producer of herring,

[1] 10,000 metric tons = 11,023 (short) tons = 22,046,000 lb.

TABLE I. Northwest Atlantic herring production by areas, in metric tons, for the period 1920–*Fishery Statistics of the United States*, and *Fisheries Statistics of Canada*. Years in which no suses were made in all states.

Year	United States										
	Virginia	Maryland	Delaware	New Jersey	New York	Connecticut	Rhode Island	Massachusetts	New Hampshire	Maine	Total
1920											
1921	0	0	0	78	3						
1922											
1923											
1924						<1	230	4,098	0	21,741	
1925	0	0				<1					
1926			0	107	1	<1					
1927											
1928						1	100	2,561	0	29,341	
1929	0	0	0	19	7	0	1,072	5,896	0	41,668	48,662
1930	0	0	0	299	15	0	97	3,940	27	33,548	37,916
1931	0	0	<1	181	21	0	107	3,574	4	25,304	29,191
1932	0	0	7	279	11	0	181	2,580	0	14,510	17,568
1933	0	0	0	268	34	0	334	1,621	<1	19,856	22,113
1934	164	0									
1935	<1	0	0	117	34	0	89	1,447	0	23,107	24,794
1936	210	0									
1937	0	0	0	166	2	0	89	1,313	0	22,658	24,228
1938	0	0	0	527	7	0	50	2,214	0	7,283	10,081
1939	2	0	0	565	19	<1	20	2,513	0	31,572	34,691
1940	3	0	0	857	16	<1	61	2,676	0	17,244	20,857
1941	<1	0								32,931[a]	
1942	2	0	0	888	<1	0	15	2,561	0	42,637	46,103
1943			0	992	66	2	11	1,329	0	25,941	
1944	31	14[b]	0	647	18	2	14	598	0	37,243	38,567
1945	53	79[b]	<1	712	15	2	14	705	0	41,999	43,579
1946	13	18[b]			285	47	65	929	0	36,336	
1947	63	19[b]	9	2,445	63	93	83	1,084	0	55,029	58,888
1948	95	29[b]	9	752	10	1,498	556	2,315	0	82,764	88,028
1949	37	16[b]	0	890	100	1,211	1,930	5,259	0	67,991	77,434
1950	45	15[b]	0	498	63	351	375	3,661	0	84,134	89,142
1951	36	1[b]	0	758	246	641	402	1,305	0	27,097	30,486
1952	8	2[b]	0	716	25	1,233	1,184	1,598	0	65,618	70,384
1953	<1	<1[b]	<1	307	14	1,499	984	2,032	0	45,626	50,464
1954	2	<1[b]	<1	294	145	768	477	1,303	0	65,065	59,056
Average	28	7	1	557	49	272	342	2,364	1	38,047	43,916

[a]From *Maine Department of Sea and Shore Fisheries* and *Fish and Wildlife Service* monthly reports.

[b]From *Maryland Commercial Fisheries Statistics*, Publications No. 69 and 94, with supplements for 1951, 1952, and 1953.

I.

1954. Except where noted otherwise, data are from *Fishery Industries of the United States,* census was taken are marked by dots. Figures in the Total columns are for years in which cen-

Canada						United States and Canada Grand Total	Year
Bay of Fundy	Atlantic Coast	Southern Gulf	Northern Gulf	Newfoundland and Labrador [e]	Total		
29,438	7,920	20,221	2,753	27,480	87,812	.....	1920
19,791	5,853	13,634	3,773	24,578	67,629	.....	1921
30,516	5,392	19,036	2,449	24,256	81,649	.....	1922
15,684	3,539	19,522	5,066	19,870	63,681	.....	1923
33,048	7,054	18,760	3,957	16,998	79,817	.....	1924
24,488	5,347	20,749	6,008	16,707	73,299	.....	1925
28,993	6,768	19,780	9,069	18,422	83,032	.....	1926
25,070	6,824	19,759	6,913	18,789	77,355	.....	1927
35,211	4,278	16,354	6,748	18,962	81,553	.....	1928
33,440	8,322	19,752	4,320	16,577	82,411	131,073	1929
21,783	7,060	20,102	4,037	13,315	66,297	104,213	1930
17,025	6,389	19,050	5,910	13,238	61,612	90,803	1931
13,637	5,455	17,748	6,998	11,888	55,726	73,294	1932
19,621	7,300	22,372	5,893	10,462	65,648	87,761	1933
28,155	7,164	18,665	11,146	9,339	74,469	.....	1934
27,636	8,391	19,653	7,908	12,825	76,413	101,207	1935
33,219	8,101	23,694	11,337	11,956	88,307	.....	1936
23,907	7,355	20,331	12,143	11,855	75,591	99,819	1937
23,592	9,164	23,089	13,402	13,187	82,434	92,515	1938
39,218	9,079	21,547	10,925	22,609	103,378	138,069	1939
31,861	9,351	22,254	13,834	18,414	95,714	116,571	1940
48,719	9,696	19,441	9,608	14,956	102,420	.....	1941
40,690	13,186	20,200	12,391	23,623	110,090	156,193	1942
46,799	14,454	25,408	11,494	32,154	130,309	.....	1943
46,583	18,843	22,011	9,812	38,591	135,840	174,407	1944
39,383	20,225	19,480	9,812	60,205	149,105	192,684	1945
57,313	20,423	26,656	8,985	74,300	187,677	.....	1946
54,151	18,636	29,497	6,310	46,106	154,700	213,588	1947
48,439	13,703	34,073	6,320	51,692	154,227	242,255	1948
34,377	16,765	26,595	6,510	27,553	111,800	189,234	1949
46,695	16,286	34,880	6,783	25,827	130,471	219,613	1950
38,118	13,198	37,615	5,485	27,056	121,472	151,958	1951
45,274	17,125	40,164	5,907	24,391	132,861	203,245	1952
29,538	15,423	32,541	7,473	17,091	102,066	152,530	1953
33,636	13,080	31,611	5,985	23,095	107,407	166,463	1954
33,287	10,490	23,321	7,642	23,953	98,693	147,500	Average

[e]From *Markets and Economics Service,* Department of Fisheries (Newfoundland and Labrador).

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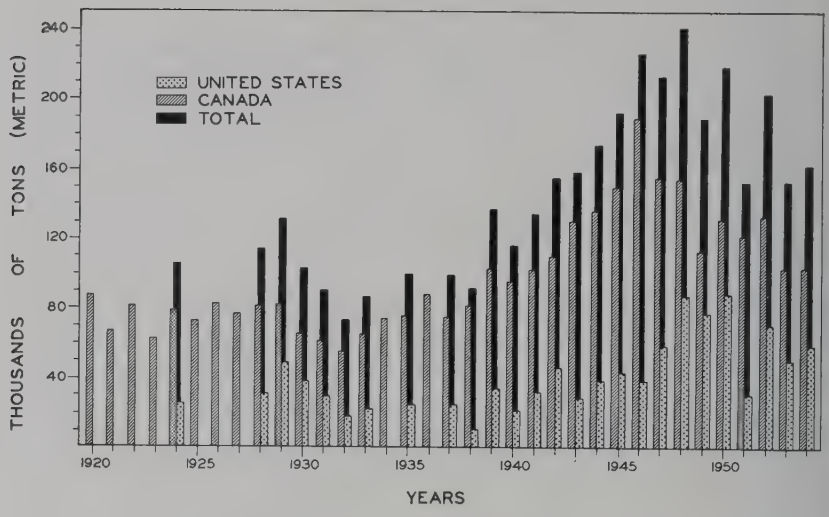

FIG. 6. Annual landings of herring in the northwest Atlantic, 1920–1954.

and the fluctuations in the United States catch are caused primarily by the varying catches in that state. Following an extremely low yield of herring in 1938, the yearly United States catches increased to a level generally above that of the 1920's and 1930's. Considering both the Canadian and United States catches during recent years, it is evident that the yield of the fishery during the present period beginning in the 1940's is much greater than in the preceding two decades.

The yearly catches are influenced by both economic and biological factors. Consequently, as comparative measures of the abundance or availability of the fish, the yearly catch figures must be used with considerable caution and only with some knowledge of the conditions that may affect the production.

The economic factor is an important influence on the size of the yearly catches. In many years, the landings reflect the size of the demand for herring to be used as bait or for herring products, which include pickled herring, smoked herring, fish meal, and canned items such as sardines, kippers, cat food, and herring in mustard or tomato sauces. The amounts of herring landed are also dependent to a great extent on the prices paid to the fishermen for herring, and these prices fluctuate with the domestic and imported supplies available to the distributors. Competition with processed herring or sardines imported from European countries affects the landings; in the face of this competition, it has sometimes been difficult for Canadian or United States processors to pay enough for raw herring to stimulate fishermen to catch these fish. For example, prior to the period in the 1940's when the pilchard fishery of western North America collapsed, California pilchards offered strong competition in both the domestic

and foreign sardine markets and thus influenced, in Maine and New Brunswick, the size of the sardine pack, the price of raw sardines and the quantity of herring landed.

Biological factors affect catches by influencing the abundance and availability of the herring. Poor survival of the young herring is reflected in small year classes of sardines, and the landings often decline accordingly. A succession of poor year classes means that recruitment to the large, mature populations will be below normal, and this in turn can affect the catches of adult fish. The disease organism *Ichthyosporidium hoferi* also appears to be a factor that governs the size of the herring populations in parts of the Gulf of St. Lawrence (Sindermann, in press). While the influence of hydrographic conditions on the availability of the northwest Atlantic herring has not yet been clearly demonstrated, we feel that the varying seasonal and geographic occurrences of this species may depend upon prevailing oceanography. As a possible result, herring may, in some years, fail to appear at the usual time in the waters of a particular region. Since the fishery operates in rather localized, inshore waters and there is little exploration to discover offshore schools, it may be possible for landings to decline although the herring populations are relatively unchanged.

The period 1941 to 1947 is a rather exceptional one, for it represents a time when the demand for herring was practically unlimited, because of Canadian and United States Government orders for large quantities of herring, both salted and canned. However, the catches of herring during those seven years must not be considered as the maximum yields possible, because the processors and fishermen were both handicapped by war and post-war conditions. In some instances, the labor supply at the canneries or salting establishments was insufficient to handle the catches, and fishing had to be restricted. This problem is not now so acute in the sardines-producing areas, for there is an increased number of fish meal plants that can utilize much greater quantities of herring than was previously possible.

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SEASONAL NATURE OF THE FISHERY

Herring fluctuate greatly in availability from season to season and year to year. In most parts of their range the herring usually appear regularly and, if a suitable market exists, the fishermen are ready to harvest them when they arrive. Occasionally, however, because of changes in their habits or migratory patterns, these fish may not be available on the customary grounds, and the local fishery for them may be a failure.

In general, south of Cape Cod, Massachusetts, landings are made during December to May, while in the Gulf of Maine and the Bay of Fundy, the fishery is most active during May to November, when one- and two-year-old fish are taken for canning as sardines. Along the Atlantic coast of Nova Scotia, the fishery is most productive in July to September. In the Gulf of St. Lawrence, the April and May fisheries predominate, while at Newfoundland the greatest catches are made in the winter and spring. Except for the Maine and Bay of Fundy fisheries, most of the herring caught are large and mature.

Table II shows the average monthly herring catches for five states and ten Canadian areas during 1945-1954. The monthly distribution of the catches for Maine and the Canadian regions is based on data published monthly during the entire period; for the other four states, the average monthly production is calculated from the total yearly catches during the 10-year period and from the monthly landings obtained over a briefer period. Information from this table is illustrated in Fig. 7-9.

TABLE II. Monthly herring landings, in metric tons.
Average for the period 1945–1954[a]

UNITED STATES

Month	New Jersey[b]	New York[c]	Rhode Island[d]	Connecticut[d]	Massachusetts[e]	Maine[f]	Total
January	141	1	197	239	1	1	578
February	20	3	255	308	1	190	776
March	122	2	44	53	2	303	526
April	370	54	58	70	160	17	729
May	53	34	20	24	525	2,226	2,882
June	3	1	4	5	85	8,596	8,693
July	3	—	1	1	50	10,144	10,197
August	—	—	1	1	123	10,242	10,365
September	1	1	1	1	440	7,395	7,837
October	1	—	4	5	182	10,067	10,258
November	8	2	11	13	339	5,348	5,721
December	99	1	13	16	113	804	1,046
Average Yearly Catch	819	97	607	734	2,019	55,332	59,608

See footnotes, page 15

TABLE II. *(Concluded)*

CANADA[g]

Month	N.B. Bay of Fundy	N.S. Bay of Fundy	N.S. Atlantic Coast	N.S. Gulf	P.E.I.	Magdalen Is.	N.B. Gulf
January	960	5	—	—	—	—	—
February	1,069	11	—	—	—	—	—
March	1,479	89	10	—	—	—	—
April	1,016	37	385	53	230	3,083	853
May	1,540	234	867	200	1,960	6,133	15,202
June	2,740	940	865	76	90	411	275
July	6,143	1,404	4,173	14	6	22	18
August	8,937	997	5,050	25	29	6	1,060
September	7,519	355	3,419	64	94	3	579
October	4,581	155	750	14	14	—	22
November	2,147	62	243	2	3	—	<1
December	699	4	7	—	1	—	—
Average Yearly Catch	38,830	4,293	15,769	448	2,427	9,658	18,009

CANADA

Month	Gaspé P.Q.	North Shore P.Q.	Nfld. and Labrador[h]	Canada Total	Canada and United State Total
January	—	—	1,680	2,645	3,223
February	—	—	318	1,398	2,174
March	—	—	823	2,401	2,927
April	104	1	3,392	9,154	9,883
May	3,552	32	3,271	32,991	35,873
June	906	49	584	6,936	15,629
July	900	13	86	12,779	22,976
August	722	35	98	16,959	27,324
September	546	65	146	12,790	20,627
October	235	18	215	6,004	16,262
November	83	<1	2,789	5,329	11,050
December	—	—	1,562	2,273	3,319
Average Yearly Catch	7,048	213	14,964	111,659	171,267

[a]The average yearly catch is from *Fishery Statistics* of the *United States* for the years 1945–1954.

[b]Monthly distribution is based on 1952–1956 *New Jersey Landings.*

[c]Monthly distribution is based on 1954–1956 *New York Landings.*

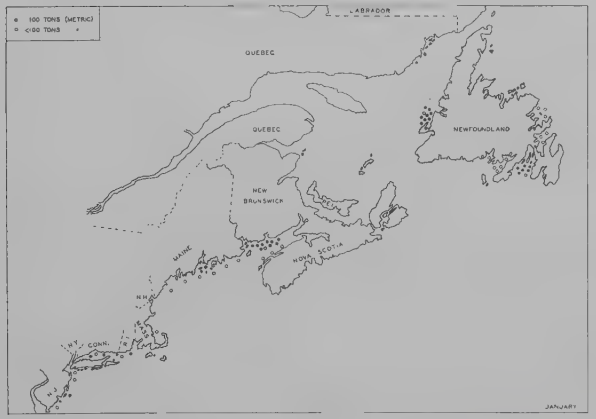
[d]Monthly distribution is based on 1954–1956 *Rhode Island Landings.*

[e]Monthly distribution is based on 1947–1955 *Massachusetts Landings.*

[f]Monthly distribution is based on 1945–1954 *Maine Landings.*

[g]Monthly figures are from FSI reports of Canadian Department of Fisheries, except for Newfoundland and Labrador.

[h]Monthly distribution is based on Canadian Department of Fisheries' Markets and Economics Service reports for year 1953–1956.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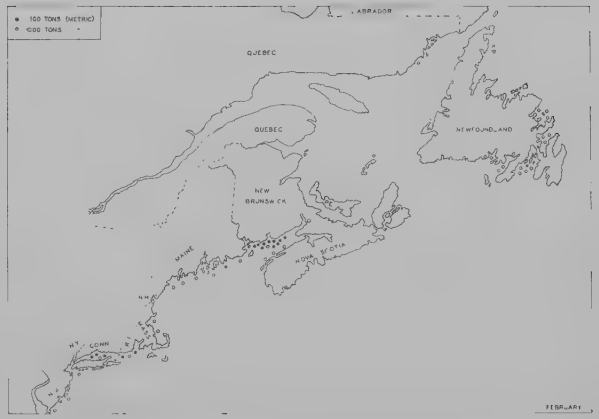
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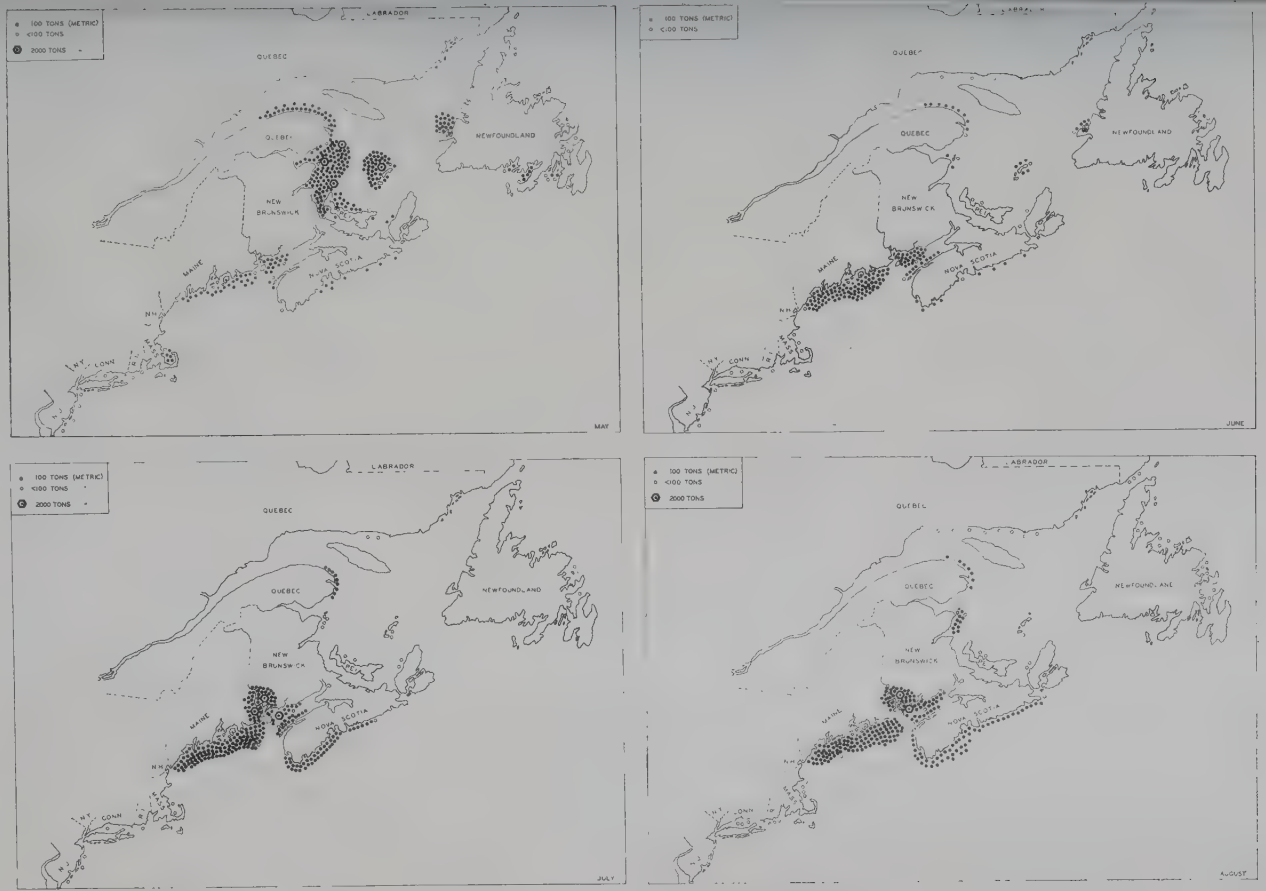


FIG. 8. Distribution of herring landings by month. 10 year average, 1944–1953 (May-August).

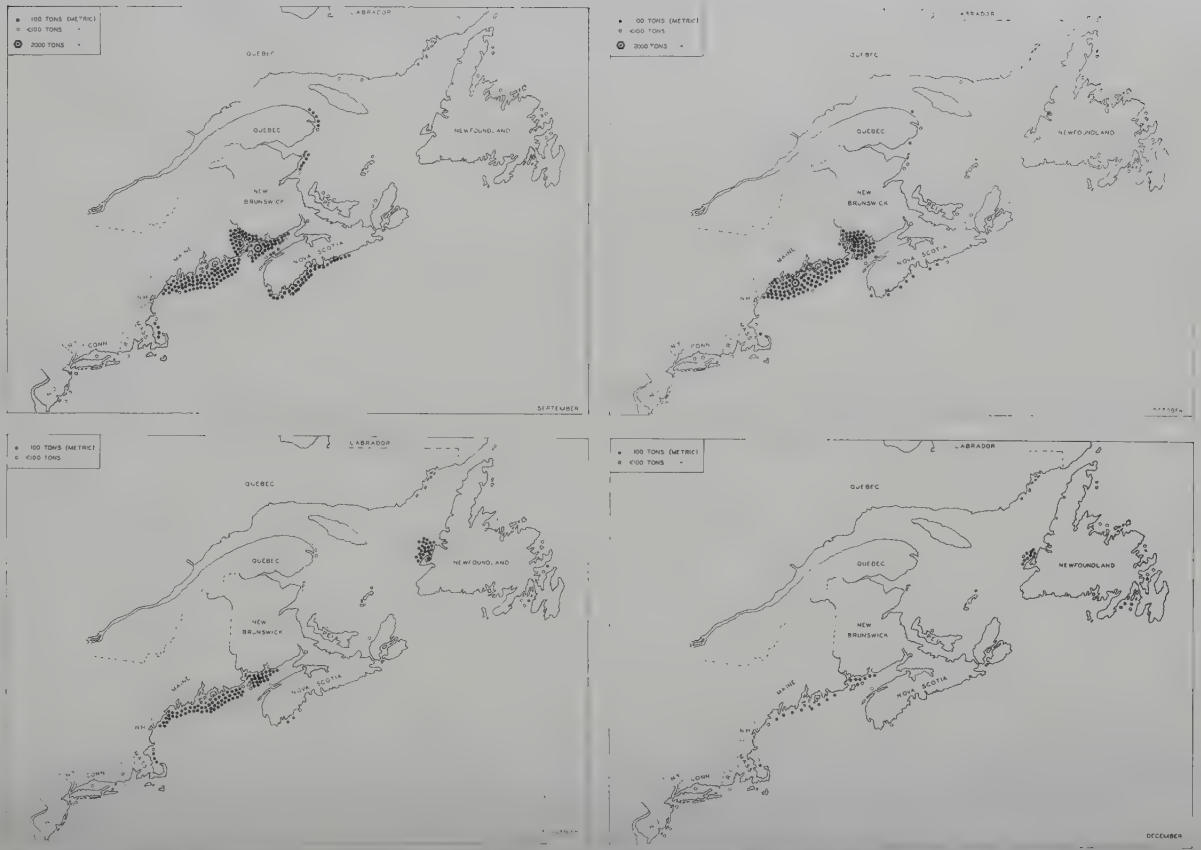


FIG. 9. Distribution of herring landings by month, 10 year average, 1944–1953 (September–December).

Herring are taken in the states south and west of Massachusetts during the colder parts of the year. Most of New Jersey's herring are caught during December to May; New York's catch is in April and May; and Rhode Island and Connecticut fishermen capture most of their herring in December to April. New Jersey has a pound net fishery throughout the year, so that her catches reflect to some extent the availability of herring along her inshore areas during the year. New York has had pound nets in action only for short periods in December and usually none in the winter and early spring until April. In Rhode Island and Connecticut, otter trawl fleets of small boats operate throughout the year, and pound nets are fished between April and November. Consequently, we may assume that limited quantities of herring are taken south of Massachusetts during the months of June through November because there are few of this species in the coastal areas.

In Massachusetts, herring are seldom caught during the period January to March. When pound nets begin to operate in April and May, the catches increase. In the summer, the herring landings diminish and, in the autumn, increase again. Often throughout the summer and, particularly in the autumn, sardine herring are taken by torching. Otter trawlers, principally on Stellwagen (Middle) Bank, often land large herring during August to October, and Massachusetts purse seiners, operating off the New Hampshire coast, land mature herring between September and December. In Massachusetts, there is no organized fishery for the small herring that may be abundant in the summer. Several times in the past, sardine canneries have been established there, but the supply of young herring was not dependable, and the operations were abandoned after a few years. We may assume that great numbers of sardine-sized herring do not occur regularly for any long period of time in the waters of that state.

In Maine, the fishery seldom takes herring in January, but is sometimes active during the rest of the year. During the period 1945-1954, there were several years when Maine's closed season for sardine-canning was relaxed to enable the canneries to pack as many fish as possible. In those years, herring were caught in February, March and April. Under the present law, herring can be canned only between April 15 and December 1. Because most of the Maine herring are used for sardines, this law has a definite effect on the seasonal distribution of the catches. The appearance of large numbers of sardines along the Maine coast between December and April is not customary, however, so that the legal season restrictions in most cases do not influence markedly the seasonal availability of the fish as indicated by the monthly landings. As shown in Table II and Fig. 7-9, the Maine fishery for herring is principally a late spring to late autumn operation.

In Canada, the herring fishery is carried on throughout the entire year, but not in all areas (Table II, Fig. 7-9). In the Bay of Fundy region, the catch is composed almost entirely of juvenile herring, and approximately one-third of the total Canadian Atlantic catch is made on the western side of the Bay in Charlotte and Saint John Counties. The fishery in this area is most productive

from July to October, and 70% of the landings are made during these four months. There is a late summer-spawning stock that is exploited in the Grand Manan area, but apart from this the fishery is almost entirely for one- and two-year-old herring. Brush weirs yield most of the catches during the period from May to October; purse seining, stop or shut-off seining, and beach seining operations are responsible for the majority of landings during the remainder of the year. Availability of the fish, weather conditions, and market demand are the most important factors in the seasonal distribution of catches; recruitment of a new year-class during the late summer and autumn undoubtedly contributes to increased landings then. In contrast to the situation in the neighbouring state of Maine, there are no seasonal restrictions in the processing of herring in New Brunswick, and canneries remain open throughout the year when adequate supplies of raw materials are available. Lack of a regular supply of herring, however, will force some canneries to close, and thus the activities of the winter purse seine fishermen will be restricted.

FIG. 10. Sardine carriers at Black's Harbour, N.B. (Photograph by National Film Board of Canada, courtesy Connor's Bros. Limited, Black's Harbour, N.B.)

On the Nova Scotia side of the Bay of Fundy, the herring fishery is very similar to that in southern New Brunswick, except that the landings are much smaller. The fishery is chiefly in Digby County, with catches becoming progressively smaller towards the head of the Bay. Approximately 86% of the catches are made from June to September inclusive (Table II), and fishing methods are the same as in Charlotte and Saint John Counties. It is difficult

to determine whether landings reflect abundance in this area. The principal markets are in New Brunswick and Maine where raw Digby County herring can be sold only if the fish are scarce in areas closer to the canneries and reduction plants.

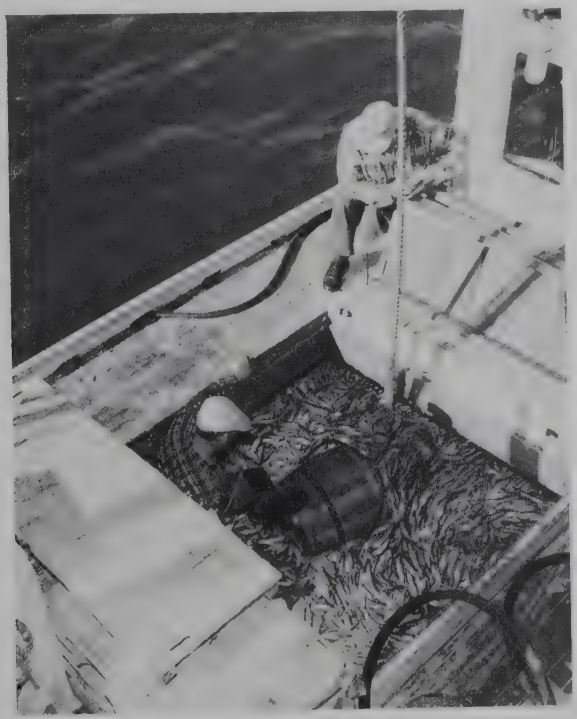


FIG. 11. Unloading sardines at a Canadian cannery. (Photograph by P. W. G. McMullon, courtesy Connor's Bros. Limited, Black's Harbour, N.B.)

On the Atlantic coast of Nova Scotia, the herring fishery is most productive in the summer and early fall months. It is based on aggregations of prespawning and spawning stocks that are taken chiefly with anchored gill nets close to the shore (Tibbo, 1957b). During the 1920's there was some drift netting and purse seining for herring in the spring, particularly along the western part of Nova Scotia, but such activities are rare now.

The major herring fisheries in the Gulf of St. Lawrence are carried on during a spawning migration in April and May. There is also an autumn-spawning stock in Gaspé and Chaleur Bay that supports small scale gill net fisheries in those areas, and some catches of immature fat herring are made with drift gill nets throughout the summer months. Sardine-sized herring are taken during the spring with weirs near the entrance to the Saguenay River at Ile Verte (Day, 1957a).

The Newfoundland herring fishery is centred chiefly in Bay of Islands on the west coast, and Fortune Bay on the south coast. Some herring are taken during every month of the year, but for any one area, the fishery is seasonal and in most cases, occurs near the spawning time. It is, however, essentially a winter and spring fishery (Tibbo, 1957c). Herring are available inshore during the late autumn and remain until they spawn the following spring. In Placentia Bay and along the east coast, there are small fisheries that are most active during the spring-spawning season. Prior to 1920, there was a large herring fishery on the east coast of Newfoundland and centered in Notre Dame Bay. This fishery was abandoned because of poor market conditions at that time and has not been revived to any great extent.

FIG. 12. Loading a large drift-net catch in the Gulf of St. Lawrence. (Photograph by E. G. Sollows.)

In Labrador, herring occur at various points along the coast between the Straits of Belle Isle and Cape Harrison. Most of the fish are caught during the summer, after their spring-spawning. They are taken close to the shore with floating traps and anchored gill nets, chiefly by vessels engaged in the cod fisheries of that area. The fishery is erratic and has at no time been very extensive. Attempts to develop a herring meal and oil industry during the early 1940's failed because of irregular supplies of fish. Seasons are characterized either by great abundance of herring or by complete failure of the fish to appear on the coast.

FISHING GEAR

In the seventeenth century, when the early colonists arrived in eastern North America, several types of herring fishing gear were being widely used in Europe. Gill nets, seines, and weirs had been in use there for centuries before the settlement of Canada and the United States, and although other types of gear have since evolved, these old apparatuses are still important for capturing herring. Table III shows the United States Atlantic catch by gear and states for the period 1945-1954. It is apparent that the stop seine, weir and purse seine account for over 93% of the total catch. Comparable data are not available for Canada, but our observations indicate that weirs are the most important gear for the sardine-sized fish in southern New Brunswick. Elsewhere in Canada the gill net dominates, with relatively minor quantities of herring being caught by floating traps and by purse seine.

FIG. 13. A typical Charlotte County weir at low tide. (Photograph by P. W. G. McMullon.)

GILL NETS

The herring gill net, while now seldom used in the United States, is still one of the principal gears for herring fishing in eastern Canada. The usual net is about 35 fathoms long, 4 to 6 fathoms deep, with a stretched mesh size of $2\frac{1}{2}$ to $2\frac{3}{4}$ inches. In some areas, where the herring are generally small, the mesh size may be only $1\frac{1}{2}$ inches; in regions with large herring, the mesh size may be increased to 3 inches. Cotton is the predominant material; nylon and linen are seldom used at the present time. In Canada, the nets are usually fished

TABLE III. United States catch of herring by gear, in metric tons, for 1945–1954. Data are from *Fishery Statistics of the United States*, 1945–1954, except for Maryland for which were used 1951, 1952 and 1953 *Maryland Commercial Fisheries Statistics*, Publication No. 69 and 94, with supplements for 1951, 1952 and 1953.

Gear	Virginia	Maryland	Delaware	New Jersey	New York	Connecticut	Rhode Island	Massachusetts	Maine	Total	Percentage
Stop seine									270,115	270,115	44.6
Weir									191,214	191,214	31.6
Purse seine				3				2,238	99,426	101,667	16.8
Pound net[a]	153	117		6,970	1	1	902	7,035	1,905	17,872	3.0
Otter trawl	173	63	19	297	7,341	7,341	4,967	3,785		16,813	2.8
Dip net[b]								7,106		7,106	1.2
Haul seine				23			200			230	0.04
Gill net[c]	30	1	1	69				28	1	131	0.02
Fyke net				10						10	0.01
Total	356	180	20	7,372	966	7,342	6,069	20,192	562,660	605,158	100.0

[a]Includes floating traps.

[b]Gear used in torching.

[c]Includes drift gill nets, stake gill nets, anchor gill nets, and run-around gill nets.

singly, although occasionally two or three nets may be joined. Small boat fishermen carry on this fishery for a period of only a few weeks, and the gear is set where the mature herring are known to occur during that season. Since so few nets are used per boat, practically all the hauling is done by hand rather than by power. Most of the nets are anchored; few are used as drift nets. Perley (1850) early advocated the use of drift rather than anchored gill nets in the Gulf of St. Lawrence, for he believed that a deep-sea herring fishery was possible; however, drift netting has never been popular. Herring gill netting in North America is in strong contrast with that of Europe where long strings of gill nets are set and hauled by power from large boats equipped with sonic or ultrasonic depth sounders that help locate the fish. In Europe, the herring are actively sought over wide areas of the ocean, while in North America, the gill netter's range is limited to local, inshore regions.

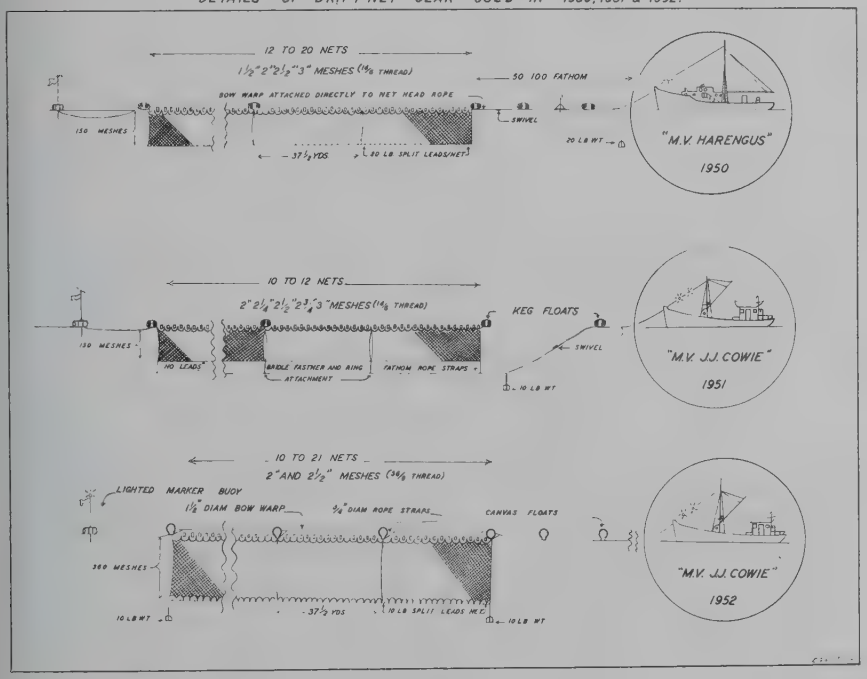


FIG. 14. Details of experimental drift-net gear used in the Gulf of St. Lawrence. (From Tibbo and Sollows, 1953.)

SEINES

Seines can be classified into two principal types; stop seines and purse seines. The one known to the colonists was the stop seine, beach seine, or drag seine. This gear is widely used for herring that visit relatively shallow water

areas. According to Earll and Smith (1889), these seines had widespread use in most areas of the Maritime Provinces prior to 1880, but were first commonly used for small herring in the Passamaquoddy region in 1884. The lengths and depths of the nets now used vary considerably. The stop seine commonly used on the Maine and southern New Brunswick coasts for immature herring is about 80 to 100 fathoms long, 6 fathoms deep, and has a stretched mesh size of $\frac{3}{4}$ to 1 inch. Several nets may be tied together, when the area to be enclosed is large. Stop seining is generally a night operation, for schools of herring are often easily detected at that time by the "firing" of the water, caused by the school's disturbing the phosphorescent marine animals. During the daytime, when the schools are not visible beneath the surface, another detection method is occasionally used. A fine steel wire with a weighted end is dropped into the water and, from the number of vibrations that result when herring swim against the wire, the fisherman is able to make a rough estimate of the density of the school. Once a school is located in a cove or inlet, a stop seine is stretched from shore to shore across the entrance to bar the exit of the fish. The school is later condensed into a more compact mass and held until the herring have completely digested any food that may have been in their digestive tracts at the time of capture.

FIG. 15. A stop seine on the Maine coast. (Photograph by Richard Merrill.)

Searching for "firings" of the water is still the most widely used means of finding herring schools; however, several newer and alternative methods have been developed and adopted by stop seiners during the past several decades. Two new techniques now allow the stop seine fishery to operate at greater efficiency during daylight hours. One is the installation on the seine boats of

sonic or ultrasonic depth recorders; these devices came into common use after World War II. When the presence of a school of fish in a cove is indicated on the depth recorder, the seiner may set his nets and have some assurance of making a successful catch, even though there are no other signs of the herring. The other development is the use of airplanes to scout for herring schools during the daytime. Once herring have been located from the airplane, the pilot directs the stop seiners to the schools and often supervises the seining operations from the air. This aerial reconnaisance has been most successful in the central and western parts of the Maine coast where the shoreline is a maze of small inlets in which herring can be caught by stop seines and where the weirs are so few that seining is not restricted in many areas.

FIG. 16. Removing "sardines" from a Maine stop seine. Fish are pumped through the hose at the right of the photograph.

PURSE SEINE

The second type of seine is the purse seine, which differs from the stop seine in two ways: first, by having on the bottom of the net a series of purse rings through which a purse line is drawn to close the lower part of the net and, second, by being handled entirely from boats, with the ends of the net not attached to the shore. This gear, developed in the United States during the 1860's, accounts for a greater production of fish than any other apparatus in North America. In the herring fisheries of the eastern coasts of Canada and the United States, however, the purse seine has never been as important as the

gill net, stop seine, or weir. The herring purse seine used on the Atlantic Coast for mature fish is about 100 fathoms long, 15 fathoms deep, with $1\frac{1}{4}$- to $1\frac{1}{2}$-inch mesh; the purse seine for smaller, sardine-sized fish is usually about the same length and depth with $\frac{3}{4}$- to $1\frac{1}{8}$-inch mesh. The purse seiners that fish for large herring locate the schools during the night-time by the "firing" of the water or by depth recorders. Few large herring are caught during the day, for even though they may occasionally be seen schooling near the surface, they then seem to avoid the nets more readily than in darkness. Purse-seining in inshore areas for the smaller fish is often effective during the winter months in southern New Brunswick and occasionally in eastern Maine, for the fish seem to be rather lethargic in the cold, relatively shallow water, where they are detected by depth recorders. During the last two decades, on the west coast of Newfoundland, large Pacific coast type purse seiners (about 80 ft long), have become increasingly important in the herring fishery and account for the major part of the catch in the Bay of Islands area.

FIG. 17. A Pacific Coast purse seiner. Introduced to the Newfoundland area in 1939. (Photograph by National Film Board of Canada.)

BRUSH WEIRS

The brush weir is a stationary type of gear that is used by both primitive and civilized people throughout the world, and it is probable that it was known to the early colonists before they arrived in North America. If this gear were perchance not known to them previously, they were soon acquainted with the Indians' use of it, for the brush weir is a simple and efficient device for capturing anadromous fish such as alewives, salmon, shad, and smelts. It is believed that the first herring weirs built by white settlers were used in Nova Scotia in the latter part of the eighteenth century. In the 1820's, this gear was introduced into Maine and New Brunswick where it was quickly adopted by the

herring fishermen. Early weirs were simple structures of wooden stakes and brush erected in relatively shallow and protected waters; more complex and larger weirs in deeper water evolved later.

The principle of the herring weir is simple. It has two primary parts; a "leader" and a "pocket" (Fig. 13, 18). The leader is a fence-line barrier that directs the fish into the somewhat circular or heart-shaped pocket or pound from which they cannot easily escape. A weir may have more than one leader and often has a secondary pound into which lots of fish are diverted for storage from the primary pound.

FIG. 18. Seining a Maine weir.

POUND NETS

The pound net of southern New England and the middle Atlantic States is closely related to the weir. It operates on the same principle as the weir, for it has one or more leaders and a pound. Between the pound and the leader is usually a heart-shaped enclosure that deflects the fish into the pound. No brush is used in its construction; netting is suspended from the stakes or piles.

FLOATING TRAPS

The floating trap is somewhat similar to the pound net. It has a leader and a pocket, but it differs from both the weir and pound nets by having neither brush nor piles; it is made of netting entirely. In the water, the net is buoyed

by floats and is held in position with anchors. The floating trap has several advantages; first, it can be used in areas where piles cannot be driven into the bottom, and second, it can be moved with comparative ease. It is a common gear in Newfoundland, Labrador, and the Magdalen Islands; a few are fished in Maine and along other parts of the United States Atlantic coast.

Otter Trawling

Although one of the most important methods for capturing groundfish, such as redfish, haddock and cod, otter trawling is only of minor importance as a herring-fishing gear. The largest concentration of otter trawling for herring is in Block Island Sound where, since the end of World War II, 50- to 60-foot long Connecticut and Rhode Island boats catch herring during the winter months when they are often available. Larger Massachusetts otter trawlers also catch herring, principally during the summer and autumn months, but as a rule these vessels avoid areas where herring are readily caught. It is seldom profitable for these larger vessels to catch herring, which is a low-priced fish, when other more valuable fish are relatively plentiful, as they are during those months. Otter trawling is of very little importance in the Canadian herring fisheries.

Torching

One of the oldest methods of catching herring in eastern North America is night-time torching or driving (Earll, 1887; Sabine, 1853). The technique and necessary gear are simple (Fig. 2). From the bow of a small boat projects a light, which in early times was furnished by burning birch bark, then later by kerosene-soaked rags, and now also by electrically powered lamps or gasoline lanterns. As the boat moves through the water, herring are momentarily attracted to the light and are dipped up by a fisherman standing in the bow. The row boats of earlier years have now been replaced by gasoline-powered craft.

This fishing method was popular up to the latter part of the nineteenth century. It was an effective means of capturing immature herring during the winter months, and much of the winter catch in the Passamaquoddy Bay region of Maine and New Brunswick was taken by this gear (Earll and Smith, 1889). Large herring are not readily captured by this method (Allen *et al.*) 1837. It is interesting to note that at the beginning of the nineteenth century, torching was the exclusive method of herring fishing at Grand Manan Island in the Bay of Fundy (Donaldson *et al.*, 1837). The torchers were strongly opposed to the use of gill nets, which were introduced there in the 1820's, for they felt that netting was responsible for the decline in the herring catch in the 1830's. Torching later became illegal in many areas of Canada and the United States. Operators of other herring gear claimed, probably with little or no evidence, that torching dispersed the herring schools, and laws were passed to prohibit this practice. Although once a common means of catching herring in Massachusetts (Storer, 1839), large scale torching now survives only in Ipswich Bay and that is restricted by the lack of a demand for more than relatively small amounts of fish for fresh consumption.

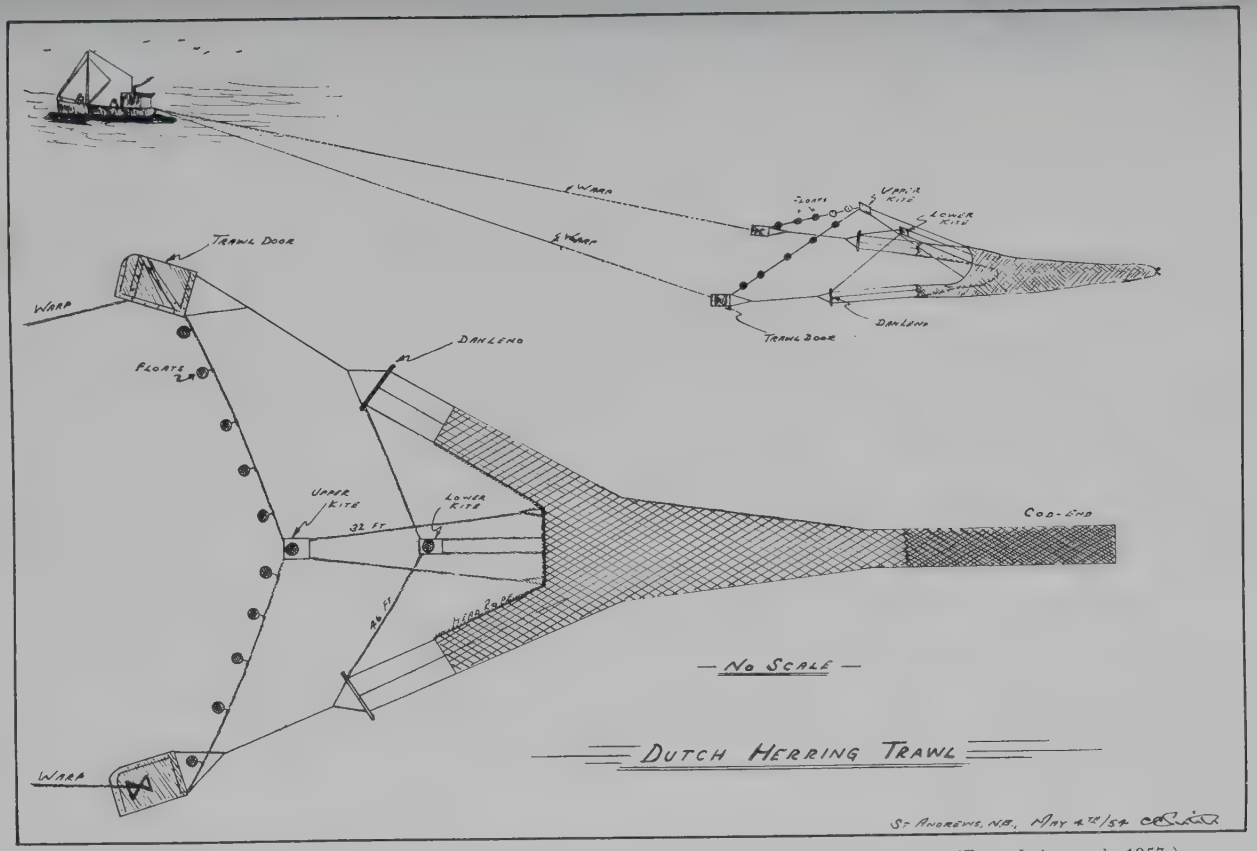


FIG. 19. Diagrammatic illustration of the construction and operation of a Dutch herring trawl. (From Leim *et al.*, 1957.)

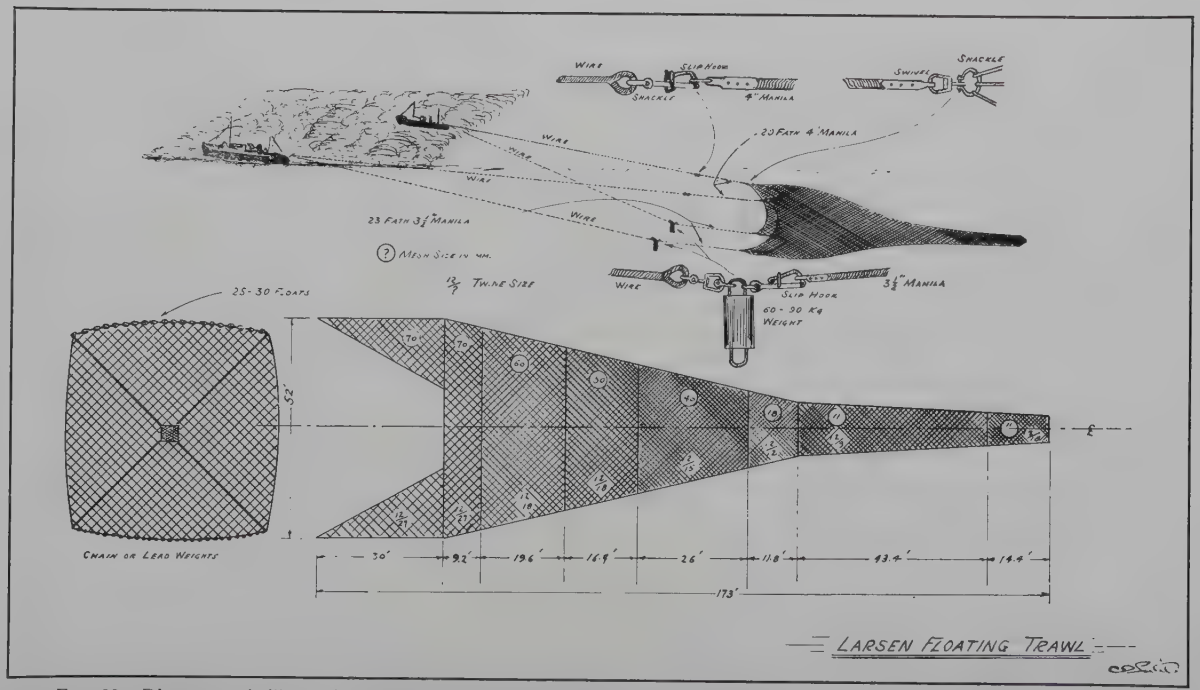


FIG. 20. Diagrammatic illustration of the construction and operation of the Larsen "floating" trawl. (From Leim *et al.*, 1957.)

UTILIZATION OF CATCHES

In the middle Atlantic section of the United States, the catches of herring are quite small. The fish are often marketed in a fresh condition, or they may be sent to fish meal plants if there is little immediate demand for the fresh fish. In New Jersey, the largest producer of herring in the middle Atlantic region, some of the fish are also frozen and sold as food for freshwater trout. In New York, where large quantities of pickled herring are imported to meet the demand, there is little effort to process the catch for human consumption, because quantities of herring landed vary considerably from year to year and would not profitably support a processing industry.

FIG. 21. Typical herring smoke house at Grand Manan. (Photograph by Dr. A. H. Leim.)

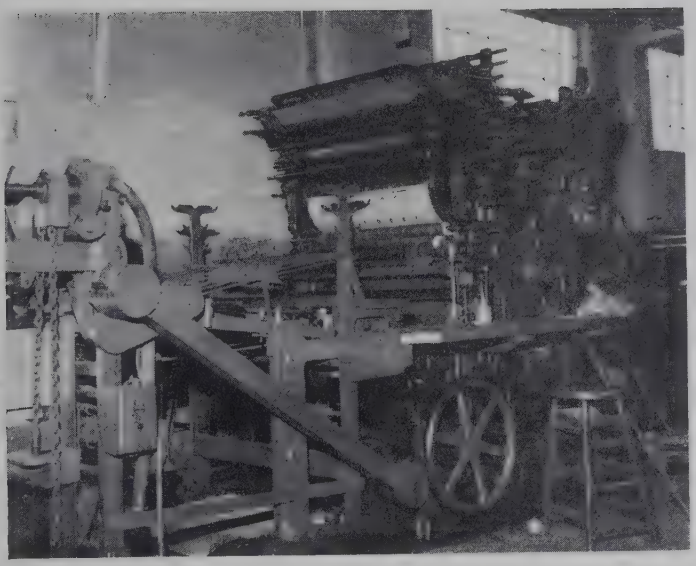
The New England states are relatively large producers of herring, which are utilized in a number of ways. In Rhode Island and Connecticut, most of the herring are sold for processing as fish meal and canned cat food, varying quantities are frozen as food for fur animals, especially mink; and small quantities are shipped to metropolitan areas to be sold fresh for human consumption. Massachusetts herring are marketed in a somewhat similar fashion. During World War II, some herring were canned as sardine and kippered snacks, but such operations in peacetime are seldom profitable in that state because of labor costs, lack of a dependable supply of fish, and competition from similar products that are more cheaply produced in Maine and foreign countries.

In Maine, most of the herring are used as sardines. Under present state legislative acts, it is illegal to catch and market herring under 4 inches in length

or to sell any herring for reduction purposes unless they are first offered to sardine-processing plants. These laws restrict the use of Maine herring for reduction; however, Maine fish meal plants are able to use small herring from Canada where no size regulations are in effect. Consequently, in Eastport, Maine, where most of the reduction plants are located, the preponderance of fish meal is derived from Canadian fish. Maine smokers and cat-food canners also depend to a great extent on imports of large Canadian fish, and this has been particularly true during the last ten years when large local herring have been quite scarce in the usual fishing areas. The absence of these fish has severely affected the pickled herring industry that flourished during World War II and for several years after. As an example of the present status of the utilization of Maine herring, 1956 statistics show that 90% by weight are canned as sardines, 8% are used as bait for the lobster fishery, and 2% for cat-food, fish meal, and smoked and pickled products. A by-product of the Maine and New Brunswick fishery is pearl essence, which is manufactured from the guanin crystals found on herring scales. The demand for pearl essence varies sharply from year to year and prices for scales may fluctuate from a few cents to over a dollar a pound. In the last few years, there has been only a limited market for scales.

FIG. 22. Loading sardines from a weir into a carrier. (Photograph by National Film Board of Canada.)

In southern New Brunswick, the fishery is chiefly for immature herring. Most of the catch is canned as sardines, with the remainder used for lobster and groundfish bait or exported fresh. In recent years, a greater proportion of



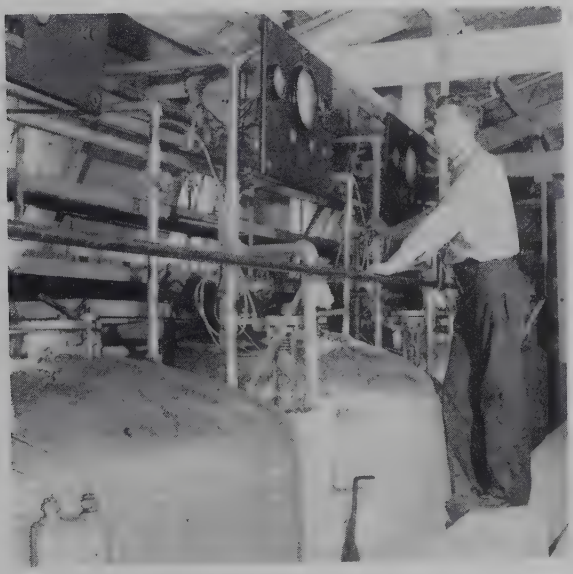


FIG. 23. The interior of a sardine cannery.
Above: A two-colour tin plate lithographing press.
Below: Steam retorts.
(Photographs by P. W. G. McMullon, courtesy Connor's Bros. Limited, Black's Harbour, N.B.)

the catch of sardines has been sent to Maine canneries and reduction plants. For example, in 1928 the total catch in Charlotte County amounted to 25,342 metric tons of which 80% was canned locally and the remainder sold as fresh or salted, whereas in 1946 from the total catch of 43,273 metric tons, 30,572 metric tons (71%) were exported fresh.

On the Atlantic coast of Nova Scotia, the herring fishery has been chiefly secondary to the groundfish fishery, with the majority of landings used for bait. With the post World War II conversion to otter trawling, the demand for herring for bait has declined, and recently most of the catch has been sold for food products (Tibbo, 1957b). Since 1950, there has been a considerable expansion in the herring fisheries of southwestern Nova Scotia, particularly in the Yarmouth, Shelburne and Queens County areas. The present catch (ca. 19,000 metric tons) is more than double the 1948 catch (ca. 7,600 metric tons). This is due to an increase in the demand for both large and small herring. Increasing quantities of the large herring are cured in vinegar and salt or are exported in fresh condition to Maine cat-food canners and reduction plants. The small herring are sold to Maine and New Brunswick sardine processors; some may also be used for reduction or cat food.

FIG. 24. Packing sardines in a Maine cannery. (Photograph by Richard Merrill.)

In the southern Gulf of St. Lawrence, where from 23,000 to 27,000 metric tons are caught annually, 60% to 80% of the herring catch has been used for smoked bloaters and canned round herring and kippered snacks (Day, 1957b).

Since 1953, there has been a change in the utilization of herring at the Magdalen Islands where a meal and oil plant has been established, and the majority of the catches are now sold for reduction purposes.

In Chaleur Bay between New Brunswick and Quebec, about 36% of the herring catch is used for food as pickled, canned and fresh, and the remainder as bait and fertilizer (Tibbo, 1957a).

The north shore of the Gulf of St. Lawrence has a coastline of more than 500 miles, but is sparsely populated. The average annual catch of 213 metric tons is a small but an important part of the economy of the area. About 75% of the catch is processed as pickled herring in areas between Kegaska and Blanc Sablon, and the remainder is used for bait for a groundfish fishery on the banks and around Anticosti Island between Seven Islands and Natashkwan. In the Cap Chat and Rivière à Claude area, the bulk of the catch is pickled, while at Rivière au Renaud, 60% of the catch is frozen and later used as bait for an extensive groundfish fishery (Day, 1957b).

In Newfoundland, the herring fishery has been particularly important. In 1946, for example, 57% of all fish and fishery products exported consisted of herring. Herring are used extensively for bait in the lobster and cod fisheries, and large quantities are consumed locally. Exports of herring consist of fresh and frozen, pickled, smoked and canned products, and fish meal (Tibbo, 1956). The once-important winter trade in frozen herring from both the south and west coasts of Newfoundland to the United States has disappeared, and the catches are now used for local consumption, for bait, pickled products and for reduction to oil and meal.

FUTURE EXPANSION OF THE FISHERY

The problem of increasing the world's food supplies as the population grows has been considered seriously by fishery organizations during the past two decades. Considerable thought has been given to the possibilities of expanding fisheries to harvest new or relatively unexploited fish stocks and of properly using the presently exploited stocks. There appears to be no quick solution to the world's food problems, so we can anticipate a continuing interest in increased utilization of the resources of the sea.

The herring appears to be a possible source of more protein food. Our knowledge of the present herring fisheries on the Northwest Atlantic coast of the United States and Canada indicates that we catch most of these fish in inshore waters where they are often seasonally abundant. While the herring are living in the open sea, they are relatively free from exploitation, for no organized fishery exists on the offshore grounds. The possibilties of an offshore herring fishery have been considered for a long time (Moore, 1898), and in recent years both countries have sponsored explorations designed to discover the distribution and size of the schools and the feasibility of harvesting herring when they are not available to the inshore fishermen. These explorations carried out by the Fisheries Research Board of Canada and the United States Fish and Wildlife Service have demonstrated that commercial quantities of herring exist offshore and that the landings of herring could be augmented by catching them.

Since there is a need for more protein and there are herring that are not being utilized, why does not an increased fishery develop? The answer is an economic one. There is only a limited market for fresh herring for human consumption, and the price that the processing industry is willing to pay for herring is not enough to induce fishermen to abandon other more profitable fisheries. For example, during the summer months, otter trawlers catch whiting (*Merluccius bilinearis*) on the northern part of Georges Bank, a region where herring are also abundant. The whiting fishermen often trawl large quantities of herring, which are immediately dumped overboard and fishing resumed elsewhere, because there is more money to be made catching whiting than herring. The processing industry says that it cannot pay more for herring because of competition with other products. For example, herring fish meal is competitive with other meals from various countries and other species such as menhaden and pilchards. Similarly, salted and pickled herring must compete with imports from Europe. Because of the change in food habits of North Americans, it seems unlikely that much greater quantities of fresh, smoked, or pickled herring will be consumed in the immediate future. However, with a continuing increase in population, animal protein shortages may become more evident, and the demand for herring products, both as fish meal and human food, may become great enough so that the fishery will eventually be prosecuted to the utmost.

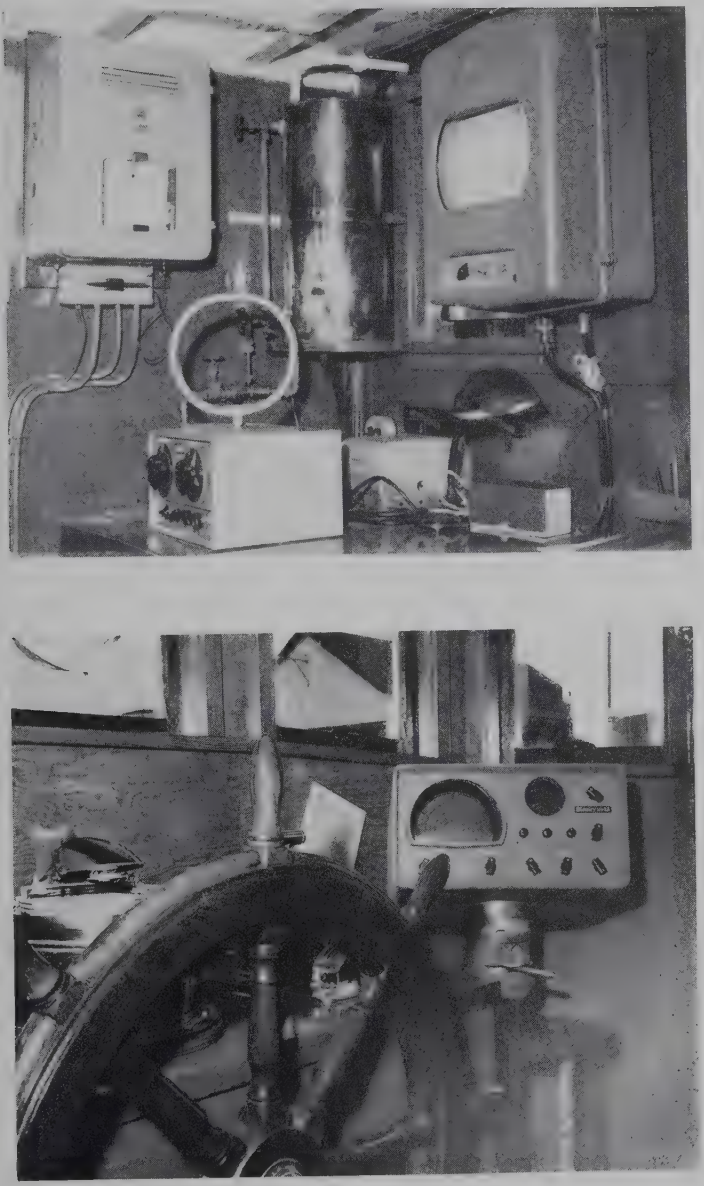


FIG. 25. Fish detection equipment on board a Canadian research vessel.
Above: Vertical sounding equipment
Below: Horizontal ranging equipment.
(Photographs by P. W. G. McMullon.)

When great quantities of herring can be landed profitably, we may anticipate that gear will be developed and improved to harvest the species in an increasingly efficient manner. Otter trawling techniques will be devised for fishing near the bottom and better mid-water trawls will be built. Old methods such as drift gill netting and purse seining may be utilized profitably, and there is the possibility that new techniques such as electro-fishing may be feasible. Improved knowledge of the general habits of herring including the locations and seasons of aggregations most suitable for fish will help substantially in making wiser use of this valuable resource.

REFERENCES

Allen, John, Thomas Barlow, John Ward, Jr., and Lauchlan Donaldson. 1837. Reports of the Commissioners appointed by the House of Assembly to procure information respecting the state of the herring fishery at Grand Manan. *J. House of Assembly New Brunswick*, 1836-37, App. No. 2 pp. XIII-XVII.

Day, L. R. 1957a. Populations of herring in the Northern Gulf of St. Lawrence. *Bull. Fish. Res. Bd. Canada*, No. 111, pp. 103-119.

1957b. Populations of herring in the Southern Gulf of St. Lawrence. *Ibid.*, No. 111, pp. 121-137.

Donaldson, Lauchlan, John ward, Thomas Barlow, James Brown, Thomas Wyer, and John Allen. 1837. Report of the Bay of Fundy deep-sea fisheries, prepared by the Commissioners appointed to inquire into the state of the herring fishery at Grand Manan. *J. House of Assembly New Brunswick* 1836-37, App. No. 2, pp. XVIII-XXXVI.

Earll, R. Edward. 1887. The herring fishery and the sardine industry. *In* G. B. Goode. The Fisheries and Fishery Industries of the United States, Sec. 5,1: 417-542.

Earll, R. Edward, and Hugh M. Smith. 1889. The American sardine industry in 1886, *Bull. U. S. Fish Comm.*, **7**: *161-192*.

Found, W. A. 1912. The lobster fishery of Canada. *In* Sea-fisheries of Eastern Canada, Commission Conservation Canada, Ottawa, pp. 50-77.

Innis, Harold A. 1954. The cod fisheries. The history of an international economy. Univ. of Toronto Press: pp. xv + 1-522.

Josselyn, Joseph. 1675. An account of two voyages to New-England. Second Addition. G. Widdowes, London. (Reprinted in *Coll. Massachusetts Hist. Soc.*, 1933, 3rd ser., **3**: 211-354.)

Leim, A. H., S. N. Tibbo and L. R. Day. 1957. Explorations for Herring in Canadian Atlantic Waters, 1945-1950. *Bull. Fish. Res. Bd. Canada, No.* 111, pp. 35-83.

Moore, H. F. 1898. Observations on the herring and herring fisheries of the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. *U.S. Comm. Fish and Fish., Commissioner's Rept. for* 1896, pp. 387-442.

Perley, M. H. 1850. Report on the sea and river fisheries of New Brunswick within the Gulf of St. Lawrence or Bay of Chaleur. J. Simpson, Frederickton, N. B. 137 pp.

Sabine, Lorenzo. 1853. Report on the principal fisheries of the American seas. Robert Armstrong, Washington, 316 pp.

Samuel, Arthur Michael. 1918. The herring; its effect on the history of Britain. J. Murray, London, xx + pp. 21-199.

Scattergood, Leslie W. 1949. The production and the fishing methods of the Maine herring industry with notes on the 1947 season. *U. S. Fish and Wildlife Serv., Spec. Sci. Rept.*, No. 67, 26 pp.

Scattergood, Leslie W., and Parker S. Trefethen. 1952. A statistical summary of the Maine herring fishery in 1948 and 1949. *Res. Bull. Maine Dept. Sea and Shore Fish.*, No. 5, 62 pp.

SINDERMANN, CARL J. (In press). An epizootic in Gulf of Saint Lawrence fishes. *Trans. 23rd North American Wildlife Conf.*

SMITH, JEROME V.C. 1833. Natural history of the fishes of Massachusetts embracing a practical essay on angling. Allen and Ticknor, Boston, pp. vii + 399 p.

SMITH, JOHN. 1624. The generall historie of Virginia, New-England, and the Summer Isles with the names of the Adventurers, Planters and Governours from their first beginning An: 1584 to this present 1624. I.D. and I.H. for Michael Sparkes, London, pp. viii + 248.

STORER, D. HUMPHREYS. 1839. A report on the fishes of Massachusetts. *Boston J. Nat. Hist.*, **2**(3–4): 289-558.

TIBBO, S. N. 1956. Populations of herring (*Clupea harengus* L.) in Newfoundland waters. *J. Fish Res. Bd. Canada*, **13**(4): 449-466.

1957a. Herring of the Chaleur Bay area. *Bull. Fish. Res. Bd. Canada*, No. 111, pp. 85-102.

1957b. Contributions to the biology of herring (*Clupea harengus* L.) on the Atlantic Coast of Nova Scotia. *Ibid.*, No. 111, pp. 139-151.

1957c. Herring populations on the south and west coasts of Newfoundland. *Ibid.*, No. 111. pp. 153-164.

TIBBO S. N., and E. G. SOLLOWS. MS, 1953. Drift-net fishing for herring, 1950 to 1952. *MS Rept., Fish. Res. Bd. Canada*, No. 505, 27 pp.

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A Major Blood Group System in Atlantic Sea Herring

CARL J. SINDERMANN AND DONALD F. MAIRS

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SINCE the first demonstration of individual differences in human erythrocyte antigens by Landsteiner (1901) and subsequent findings of racial differences in the frequencies of particular antigens (summarized by Mourant, 1954), intensive serological studies of a number of animal species have been made. Blood group systems have been developed for cattle (Ferguson, 1941; Owen, Stormont, and Irwin, 1947; and Stormont, Owen, and Irwin, 1951), chickens (Briles, McGibbon, and Irwin, 1950; Scheinberg, 1956), and several other avian and mammalian species. Such blood groups have been found to be genetically determined, and genetic explanations for their existence and relationships have been proposed. Recent attention has been directed toward identification of infraspecific groups of marine fishes by serological methods (Cushing, 1952, 1956; Ridgway, 1957; Ridgway, Cushing, and Durall, 1958; Sindermann, 1958; Suzuki, Shimizu, and Morio, 1958). This work has demonstrated the existence of individual variations in erythrocyte antigens of certain fishes and in some cases quantitative differences in the frequency of occurrence of antigens. These differences may prove as useful to fisheries investigations as human blood groups have to anthropological studies, or as cattle blood groups have to problems of lineage. If genetic distinctions exist among populations or races of marine fishes, as they have been found to exist in other animal species, certain of them may be disclosed by serological methods, and may be of value in population and migration studies.

With this point of view in mind, a study has been made of erythrocyte antigens of Atlantic sea herring (*Clupea harengus*), to determine if individual variations exist, and, if so, whether fish from different areas might be distinguished by different frequencies of particular antigens. Stocks of immature Gulf of Maine herring have been of principal concern, largely because of their economic importance and availability in quantity. The study reported here has been designed to discover whether or not they constitute one homogeneous group, or whether they may represent several more or less discrete groups.

MATERIALS AND METHODS

Blood samples were taken from immature herring of age groups 1 and 2 in summer and autumn of 1957 and 1958. More than 800 individual fish were bled, from catches which ranged geographically from Kennebunkport, Maine, to Saint Andrews, New Brunswick. Blood was obtained by cardiac puncture using a glass needle technique developed in this laboratory (Perkins, 1957) and was either citrated or allowed to clot. Cells from citrate tubes or clots were washed 3 times in 1.5 percent saline and used in approximately 4 percent suspensions in saline. Preliminary work involved testing herring cells with a variety of normal sera (cod, haddock, lamprey, sheep, horse, lobster, alewife, cattle, rabbit) to see if individual differences in reactions could be detected. Cell agglutination tests were also attempted with antisera prepared in rabbits and chickens by injections of pooled and individual samples of washed herring cells, as well as cod, lamprey, and alewife cells. Tests were run at room temperature within 72 hours from the time the blood was taken, although reactions of refrigerated cells did not change noticeably up to 10 days. Tube agglutination tests were made, using 0.2 ml. serum dilution and .05 ml. of 4 percent cell suspension. Readings were taken after 15 minutes incubation at room temperature and 30 seconds centrifugation.

Normal lobster (*Homarus americanus*) serum and rabbit anti-herring serum provided most definitive separation of individual her-

ring samples, and these reagents were used in later quantitative studies. For this quantitative work a pool of serum from 12 lobsters (labelled BHL2) was used throughout. This pool was frozen in small aliquots and was thawed just prior to use. A rabbit antiserum, prepared by injecting pooled washed cells of 50 Nova Scotia herring, and labelled NSFH16R was also used throughout. As with the lobster serum, this antiserum was frozen in small aliquots which were thawed and heat-inactivated to destroy complement activity just prior to use.

Demonstration of Erythrocyte Antigen C

Marked individual differences in reactions of herring cells were detected with lobster serum and rabbit anti-herring serum. Erythrocytes of most fish were strongly agglutinated by lobster serum (BHL2) to dilutions of 1:128, and by rabbit anti-herring serum (NSFH16R) to dilutions of 1:1024. Cells of certain herring, however, were not agglutinated by lobster serum beyond the 1:4 dilution, or by the rabbit antiserum beyond the 1:32 dilution. Differences of this magnitude suggested real variation in the antigenic content of herring erythrocytes. Table 1 illustrates the types of reactions found. The degree of agglutination was recorded conventionally in descending order from 4,

Table 1

Reactions of Rabbit Anti-herring Serum (NSFH16R) and Lobster Serum (BHL2) with Erythrocytes of Ten Individual Herring from the Isles of Shoals, Maine

Rabbit anti-herring serum (NSFH16R) dilutions	Erythrocytes of individual herring									
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
1:64	4	0	4	4	0	4	4	4	4	3
1:128	3	0	4	4	0	3	4	4	3	2
1:256	3	0	4	3	0	2	4	3	2	2
1:512	2	0	3	2	0	1	2	2	1	1
1:1024	2	0	1	2	0	0	1	1	1	1
Lobster serum (BHL2) dilutions										
1:8	4	0	4	4	0	4	4	4	4	3
1:16	4	0	3	4	0	3	4	3	3	3
1:32	3	0	3	4	0	3	3	3	3	2
1:64	2	0	2	3	0	2	2	2	1	1
1:128	2	0	1	2	0	0	1	0	1	1

Table 2

Results of Absorbing Rabbit Anti-herring Serum (NSFH16R) with Erythrocytes of Five Individual Herring from the Isles of Shoals, Maine

Antiserum NSFH16R absorbed with erythrocytes of individual herring	Erythrocytes of individual herring									
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
#1	0	0	0	0	0	0	0	0	0	0
#2	2	0	2	2	0	1	1	2	1	1
#3	0	0	0	0	0	0	0	0	0	0
#4	0	0	0	0	0	0	0	0	0	0
#5	2	0	3	1	0	1	1	2	1	1

representing complete agglutination, to 0, indicating no agglutination.

Cells from fish numbered 2 and 5 were negative with both rabbit anti-herring serum (NSFH16R) and lobster serum (BHL2) at the dilutions used, whereas cells of other fish were clearly positive at the same dilutions. These reactions suggested the existence of at least two antigenic types—those which reacted strongly with certain antibodies in the sera used, and those which reacted weakly or not at all with such antibodies. Absorptions of the antiserum supported this hypothesis, as illustrated in Table 2. The absorptions of specific antibodies were made by incubating one part herring cells and five parts diluted antiserum at room temperature, usually for fifteen minutes. After this incubation period, the absorbing cells were centrifuged and the supernatant tested against an aliquot of the cells used for absorption. One absorption was usually sufficient to remove all antibodies reactive with antigens on the absorbing cells.

Absorption by cells of fish number 1, 3, and 4, which in Table 1 were found to be strongly reactive, removed antibodies for the absorbing cells and all others. Absorption with weakly reactive or negative cells of fish number 2 and 5 removed antibodies for the absorbing cells and other weakly reactive ones at the dilutions used in absorptions (1:10), but left antibodies which agglutinated strongly reactive cells. For ease of description, and as a first approximation of reality, the erythrocyte antigen resulting in strong reactions with unabsorbed antiserum and in agglutinations with absorbed antiserum has been labelled antigen "C." Cells

from individual fish could then be designated as "C-positive" or "C-negative." A quantity of rabbit anti-herring serum (NSFH-16R) was absorbed with C-negative cells, tested and frozen in small aliquots, and thereafter constituted a reagent for detection of the presence or absence of antigen C, since only C-positive cells would be agglutinated by it.

Geographic Variation in the Frequency of Occurrence of Antigen C

After demonstration of individual variations in herring erythrocyte antigens and development of reagents capable of clearly distinguishing C-positive from C-negative fish, quantitative studies were made of the frequency of occurrence of each type in immature herring stocks. Cells were tested with lobster serum (BHL2), unabsorbed rabbit anti-herring serum (NSFH16R), and the reagent prepared by absorbing NSFH16R with C-negative cells. The geographic distribution of samples and results of tests for the presence or absence of Antigen C are summarized in Table 3 and presented graphically in Figure 1.

With Mount Desert Island as a boundary, Antigen C occurred in 97.7 percent of "eastern" immature herring, while it occurred in only 77.0 percent of "western" herring of comparable age. Chi-square analysis ($X^2 = 9.73$, $p = .0018$) furnished evidence for a significant difference in the frequency of occurrence of the antigen in the two areas, and suggested that "eastern" and "western" stocks may originate, at least in part, from different spawning populations. The data point to the existence of two serologically distinguishable subgroups of immature Gulf of Maine herring, with a rather clear transition in the vicinity of Mount Desert Island.

Table 3

Distribution of Antigen C in Immature Gulf of Maine Herring

Area of sampling	Numbers of samples	Numbers of fish tested	Num bers of fish C-positive	Percent of fish C-positive
"Eastern" herring				
Point Lepreau, N. B. to West Quoddy Head	6	213	208	97.6
West Quoddy Head to Mount Desert Island	3	88	86	97.7
Total	9	301	294	97.7
"Western" herring				
Mount Desert Island to Pemaquid Point	3	139	111	79.8
Pemaquid Point to Cape Small	4	183	132	72.1
Cape Small to Cape Porpoise	5	192	153	79.6
Total	12	514	396	77.0

Discussion

It is difficult to obtain direct genetic information about pelagic marine fishes. Erection of blood group systems in marine teleosts, and especially the development of genetic theories to explain them, must at present draw heavily upon investigations of other animal species. This work in man, chickens, cattle, and goldfish has clearly indicated genetic determination of erythrocyte antigens. Preliminary work on other Atlantic clupeoid fishes has suggested the existence of an antigen system similar to that here described for herring. Since certain of the clupeoids—the alewife (*Pomolobus pseudoharengus*) in particular—are anadromous, with short spawning runs to restricted bodies of water, they may constitute more suitable material for direct genetic studies than marine species. However, until such evidence accumulates, differences in fish erythrocyte antigens of the nature reported in this paper for herring Antigen C, should prove to be instructive and useful as tools in population studies.

With human, cattle, and chicken erythrocyte antigen research, increasing complexity of blood groups emerged with continued investigation. This may prove to be true with fishes too, so that the system here described for herring may eventually require elaboration. That several serological subgroups or even dosage effects may possibly be included in "Antigen C" is suggested by individual differences in agglutination titer. This however, should not modify the basic findings reported in this paper.

Until more precise reagents become available, tests for the presence or absence of Antigen C have utility in their present form. They have demonstrated significant differences in the frequency of occurrence of this antigen in immature Gulf of Maine herring, and have pointed to the existence of two serologically recognizable subgroups—eastern and western. It seems pertinent here that a recently completed three-year study of parasite distribution and abundance in such fish (Sindermann, 1957*a*, 1957*b*) has pointed to

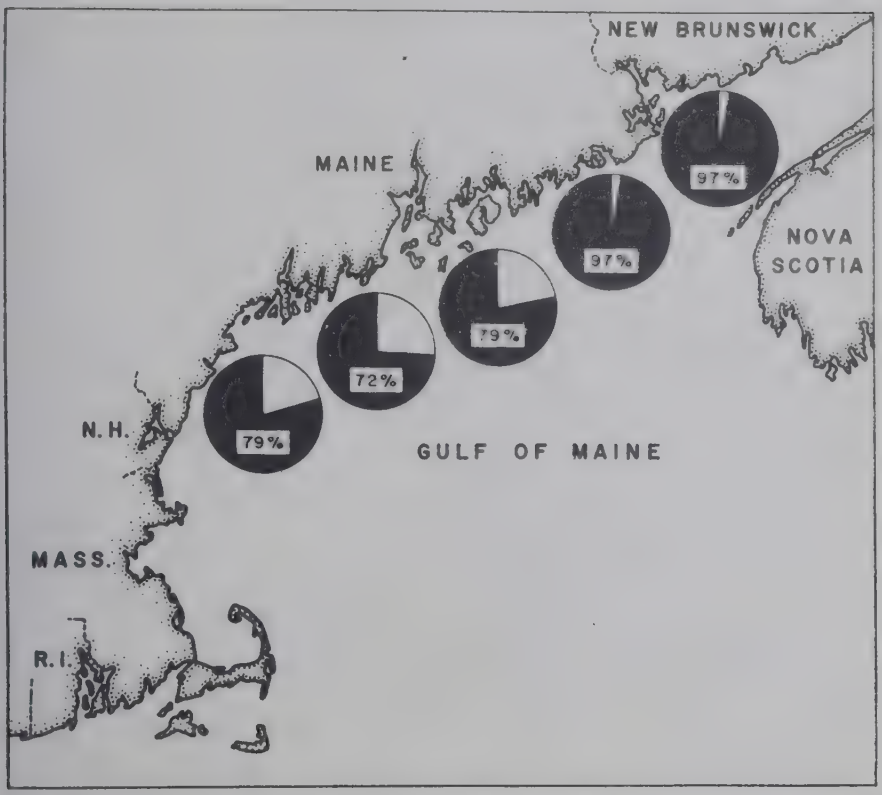

Fig. 1.—Frequency of occurrence of erythrocyte Antigen C in immature Gulf of Maine herring.

the same conclusion—the existence of two subgroups of immature herring in inshore waters of the Gulf of Maine, with an area of mixing in the vicinity of Penobscot Bay and Mount Desert Island.

Future direction for serological studies of herring seems clear. Further refinement of the C_1 system should be made; search should be continued for other blood group systems in the species; and genetic studies should be attempted, with this or a closely related anadromous species. It is also obvious that similar studies must be made of actual spawning aggregations, even though this may be more difficult because of the lack of an extensive fishery for mature herring in the Gulf of Maine. With sufficient exploration and standardization of methods, serological techniques—particularly those concerned with blood group antigens—should take their place beside the more traditional ways of studying populations and migrations of herring or any other species of fish.

Conclusions and Summary

A major blood group system in immature Atlantic sea herring has been distinguished with normal lobster serum and rabbit anti-herring serum. The erythrocyte antigen detected by such sera has been tentatively called antigen "C." Cell agglutination tests and antiserum absorptions have suggested a simple situation of presence or absence of the antigen in individual fish, so that they may be classified as C-positive or C-negative, although the possibility of subgroups in the C-positive fish remains. Population heterogeneity in immature Gulf of Maine herring has been indicated by significant differences in the frequency of occurrence of Antigen C. "Eastern" herring have an antigen frequency of 97.7 percent, while "western" herring have

frequency of only 77.0 percent. This evidence points to the existence of at least two subgroups of immature fish, probably drawn from different spawning populations, with a transition in the vicinity of Mount Desert Island—a finding which agrees remarkably well with data from parasitological studies.

Literature Cited

Briles, W., W. McGibbon, and M. Irwin. 1950. On multiple alleles effecting cellular antigens in the chicken. *Genetics 35:633–52.*

Cushing, J. 1952. Serological differentiation of fish bloods. *Science 115:404–5.*

———. 1956. Observations on the serology of tuna. *U. S. Fish Wildl. Serv., Spec. Sci. Rept., Fish. No. 183:1–14.*

Ferguson, L. 1941. Heritable antigens in the erythrocytes of cattle. *Jour. Immunol. 40:213–42.*

Landsteiner, K. 1901. Über Agglutinationserscheinungen normalen menschlichen Blutes. *Wien. Klin. Woch. 14:1132–34.*

Mourant, A. 1954. The distribution of the human blood groups. *Blackwell Sci. Publ., Oxford. xxi + 438.*

Owen, R., C. Stormont, and H. Irwin. 1947. An immunogenetic analysis of racial differences in dairy cattle. *Genetics 32:64–74.*

Perkins, F. 1957. A field technique for obtaining samples of fish blood serum. *Prog. Fish Cult. 19:144.*

Ridgway, G. 1957. The use of immunological techniques in racial studies. *U. S. Fish Wildl. Serv., Spec. Sci. Rept., Fish. No. 208:39–43.*

Ridgway, G., J. Cushing, and G. Durall. 1958. Serological differentiation of populations of sockeye salmon (*Oncorhynchus nerka* Walbaum). *U. S. Fish Wildl. Serv., Spec. Sci. Rept., Fish. No. 257:1–9.*

Scheinberg, C. 1956. Genetic studies of cellular antigens in the chicken. *Genetics 41:834–44.*

Sindermann, C. 1957*a*. Diseases of fishes of the Western North Atlantic. V. Parasites as indicators of herring movements. *Maine Dept. Sea and Shore Fish., Res. Bull. No. 27:1–30.*

———. 1957*b*. Diseases of fishes of the Western North Atlantic. VI. Geographic discontinuity of myxosporidiosis in immature herring from the Gulf of Maine. *Maine Dept. Sea and Shore Fish., Res. Bull. No. 29:1–20.*

———. 1958. Anti-mammalian erythrocyte properties of sea herring serum. *Anat. Rec. 131:599.*

Stormont, C., R. Owen, and M. Irwin. 1951. The B and C systems of bovine blood groups. *Genetics 36:134–61.*

Suzuki, A., Y. Shimizu, and T. Morio. 1958. Serological studies of the races of tuna. I. The fundamental investigations and the blood groups of albacore. *Nankai Regional Fish. Res. Lab. (Japan) Rept. No. 8:104–16.*

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278 Carl J. Sindermann and Donald F. Mairs, U. S. Bureau of Commercial Fisheries. Blood properties of pre- and post-spawning anadromous alewives.

Dramatic changes in certain of the blood characteristics of humans and other higher vertebrates often occur under such physiological stresses as acute disease or pregnancy. It might be anticipated that lower vertebrates, with less precise control of their internal environment, would exhibit equally profound changes as the external medium or physiological conditions varied. As an adjunct to continuing serological studies of marine and anadromous fishes, an assessment is being made of the extent of environmental and physiological influences on blood properties. Examination of certain blood characteristics of pre- and post-spawning alewives (*Pomolobus pseudoharengus*) has pointed to lack of extensive changes resulting from fresh-water migration and reproduction.

No important changes were noted in average sedimentation rate, erythrocyte fragility, hemoglobin content, or serum electrophoretic patterns when fish entering fresh water in May were compared with seaward migrant post-spawners one to two months later. Significant reductions were observed in averages for total serum proteins and serum chlorides of seaward migrants. Great individual variations in hemoglobin content, total serum proteins, and sedimentation rates were found in both pre- and post-spawners. Serum electrophoretic patterns were generally similar to those of other clupeoids with fractions having mobilities comparable to human albumin and alpha and beta globulins, but with little representation in the area of gamma globulins.

While short-term changes immediately associated with the act of spawning may occur, it does seem that, for most of the blood properties examined, seaward migrant alewives are not markedly different from those which first entered fresh water. Observed reductions in total serum proteins and serum chlorides of post-spawners are probably associated with the reduced salinities encountered in fresh water rather than with spawning.

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279 Carl J. Sindermann and Donald F. Mairs, U. S. Bureau of Commercial Fisheries. The C blood group system of Atlantic sea herring.

Infraspecific groups of marine fishes have long been differentiated by quantitative studies of anatomical and physiological characteristics (scale growth patterns, vertebral counts, body proportions, etc.). Most of these traditional criteria are not entirely aloof from modification by environmental factors, and often provide little real information about the geographic origin of members of the group. Partly because of limitations inherent in other methods, recent interest has developed in serological techniques, particularly those concerned with erythrocyte antigens, as additional tools for the study of marine fish populations and movements. A major blood group system has been recognized in Atlantic sea herring (Sindermann and Mairs, Copeia (in press), 1959). Further study of this system, tentatively labelled the "C" system, has disclosed that it may be demonstrated by heterophile components of rabbit anti-sheep serum, as well as by normal lobster and absorbed rabbit anti-herring serum. With each of these reagents, individual fish may be classified as C-positive or C-negative. Furthermore, the frequency of this blood group antigen varies significantly in immature herring from different geographic areas. Quantitative studies of antigen frequency in spawning populations have suggested that stocks of Gulf of Maine immature herring are drawn from at least two major spawning sources.

Since blood group systems comparable to the C system of herring undoubtedly exist in other commercial marine fish species, and since several unrelated systems may occur in such fish as they do in higher vertebrates, it seems quite probable that quantitative studies of blood group antigens will prove to be powerful tools in fish population and migration investigations, with utility similar to that of human blood groups in anthropological studies.

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AN INSTANCE OF NATURAL MASS MORTALITY OF LARVAL FRIGATE MACKEREL IN THE HAWAIIAN ISLANDS

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An Instance of Natural Mass Mortality of Larval Frigate Mackerel in the Hawaiian Islands

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Introduction

Mass mortality among larvae of the more fecund marine fishes has been commonly hypothesized but is poorly documented. Early workers ascribed a high death rate to the yolk-sac absorption stage (FABRE-DOMERGUE and BIÉTRIX, 1897; HJORT, 1914, 1926), but recent investigators have instead indicated a considerable mortality at the larva-postlarva transformation point (SETTE, 1943; MARR, 1956, on AHLSTROM and NAIR's MS.).

The existence of a critical period in the early life history has been discredited by AHLSTROM (1954), who states that the apparent mortality might be an artifact produced by net selection, and by MARR (1956), who presents a comprehensive review of the subject. MARR concludes that there is little evidence to support the critical period theory, that records of the natural occurrence of dead larvae may be artifacts, and that where mortalities are restricted in time the causes should be obvious. He qualifies this last idea by saying that "...the chances that the observer will make the right observations at the right time and the right place are greatly reduced".

This paper documents an apparently rarely observed phenomenon, the occurrence of large numbers of dead marine fish larvae. Because of the doubt which has been cast upon a natural mortality of this sort, and because of the slight chances for observing it, it is desirable to present detailed descriptions of the fish, the sampling methods, and the environment at the time of sampling. Particular attention has been paid to the question of whether the larvae were actually dead when collected.

Methods and Descriptions

During 1956 and 1957 the Pacific Oceanic Fishery Investigations (POFI), of the United States Fish and Wildlife Service, Honolulu, tested several types of plankton tows in an attempt to devise a standard method for sampling larval tuna. On 11–13. July 1957, the POFI vessel "Charles H. Gilbert" operated in

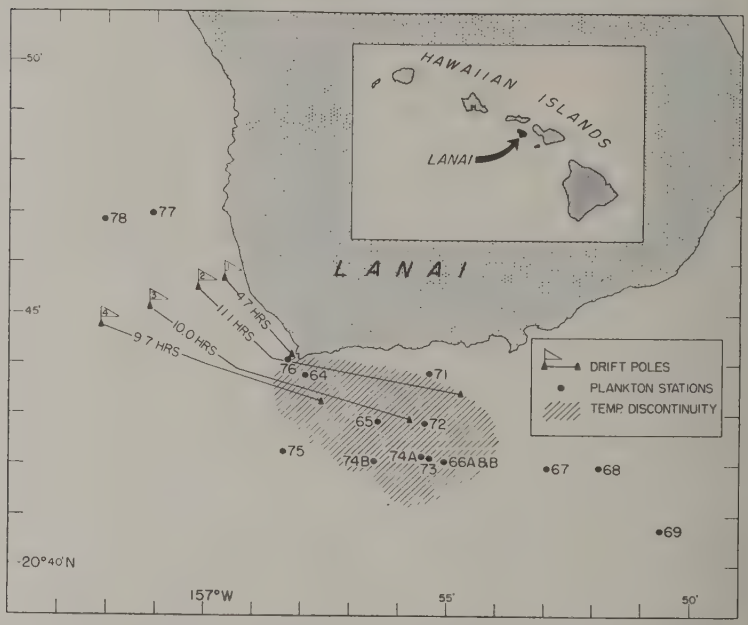

Figure 1. Lanai Island showing stations from which frigate mackerel larvae were obtained, tracks of driftpoles, and area of temperature discontinuity.

the vicinity of Lanai Island, one of the smaller members of the Hawaiian chain (Fig. 1). Here a series of half-hour plankton tows was made with a 1 m (mouth diameter) net, 5 m long and constructed of nylon gauze having mesh apertures 0·66 mm in width in the body of the net and 0·31 mm in the rear section and bag. Horizontal tows were made at the surface and oblique tows from the surface to about 60 m; in the former the net fished just beneath the surface, in the latter it was lowered and retrieved at a slow uniform rate. The vessel's speed was 2·5–3·5 knots during both tows, and the course pursued was frequently circular. A current meter in the net's mouth provided estimates of the volume of water strained. The stations, catches, and other data pertinent to these operations are summarized in Table 1.

At the end of each tow the net was rinsed with salt water to wash plankton residues into the bag. The plankton was immediately transferred to a glass jar and preserved in 10% borax-neutralized formalin. Fish and fish eggs were removed from the surface samples two weeks after collection, and from the 0–60 m samples six weeks after collection, and these were also stored in 10% neutralized formalin. At no time was there any evidence of putrefaction in the samples.

The larval scombrid fishes sorted from the collections were identified with the aid of MATSUMOTO's two recent papers (1958 and MS.), with the dominant

Table 1

Larval frigate mackerel, *Auxis* sp., captured off Lanai, 11–13. July 1957, in half-hour tows with a 1 m zooplankton net

Station	Depth (m)	Date	Time tow started	North latitude	West longitude	Number of larvae	Larvae per 1000 m³	Percentage dead larvae	Surface temp. °C	Invertebrate plankton (ml/1000 m³)
64	0	11	1924	20°43·8′	156°58·0′	77	30·8	6·5	26·6	18·5
65	0	11	2059	20°42·9′	156°56·5′	288	129·1	5·9	26·4	6·5
66A	0	11	2301	20°42·1′	156°55·1′	140	58·3	99·3	26·3	4·1
66B	0	11	2337	20°42·1′	156°55·1′	173	60·4	99·4	26·3	3·9
67	0	12	0100	20°42·0′	156°53·0′	96	41·5	18·8	26·2	5·7
68	0	12	0300	20°42·0′	156°51·9′	65	27·7	4·6	26·2	6·5
69	0	12	0501	20°40·7′	156°50·6′	210	117·6	96·2	26·2	25·5
71	0–54	12	2001	20°43·8′	156°55·4′	43	35·4	0·0	25·8	40·3
72	0	12	2046	20°42·8′	156°55·5′	1557	665·8	12·8[1])	26·5	12·4
73	0–59	12	2201	20°42·2′	156°55·5′	185	113·8	50·3	26·7	20·2
74A	0	12	2233	20°42·2′	156°55·6′	186	78·5	53·2	26·7	7·6
74B	0	12	2306	20°42·1′	156°56·6′	234	102·0	23·9	26·4	10·5
75	0–58	12	2349	20°42·4′	156°58·5′	6	3·4	16·7	26·3	18·0
76	0–62	13	0035	20°44·2′	156°58·3′	138	86·9	10·9	26·4	19·8
77	0–82	13	0133	20°47·2′	157°01·0′	30	20·9	6·7	26·2	27·8
78	0–77	13	0221	20°47·1′	157°02·0′	65	39·5	7·7	26·2	28·9

[1]) Based on a subsample of 635 fish.

form being frigate mackerel (*Auxis* sp.). The larvae of the two species of frigate mackerel occurring in Hawaii (*thazard* and a *thynnoides*-like form) are not as yet separable, and it is not known whether more than one species occurred in the Lanai collections. Not only were large numbers of frigate mackerel larvae obtained, but in many cases the specimens appeared to have been dead prior to capture. The correctness of this supposition is discussed in the following paragraphs.

Assessment of Mortality

When first examined the larval frigate mackerel were viewed against a black background with direct, overhead illumination. It was immediately noticeable that there were two distinct types: clean-cut larvae of normal appearance, and imperfect specimens with signs of physical deterioration. Further examination led to the hypothesis that these types represented fish which were alive and dead, respectively, just prior to capture. With this idea in mind all specimens were examined against a black background, and categorized as living or dead on the basis of the following characteristics: —

Living – flesh cream-coloured, opaque; vertebral column visible as a grey line separating epaxial and hypaxial musculature; visceral mass and anus turgid; eyes, jaws, and gill arches usually intact; body frequently contorted.

Dead – flesh grey, somewhat translucent; vertebral column invisible; visceral mass often lacking, when present both it and anus flabby; eyes typically absent; lower jaw prognathous; gill arches distorted; body straight.

Typical representatives of these two types are shown in Figure 2. The colour and transparency of the flesh of the "dead" fish suggest decomposition, as does the lack of eyes and distortion of the gill arches. However, the latter effects

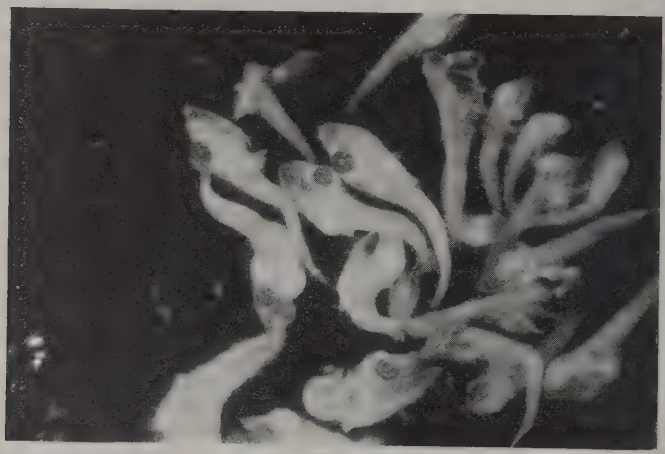

Figure 2. Typical larval frigate mackerel from Lanai. The light coloured specimens to the left were regarded as living, the darker fish to the right as dead.

could also be caused by net damage. The straightness of the body, which stands in marked contrast to the contorted attitudes of the most perfect and fresh looking larvae, implies considerable muscular relaxation, a phenomenon associated with death, at the time of preservation. The loss of the visceral mass could similarly be related to death and putrefaction, with the bloated viscera rupturing the body wall and ultimately tearing free. An increase in buoyancy, brought about by the accumulation of the gases of decay, is a logical mechanism by which dead larvae would remain at the surface to be collected. It should be noted that these larvae do not have swimbladders.

Before accepting the above hypothesis it is necessary to examine several possible causes for the condition of the damaged and "dead" larvae. MARR (1956) noted that damaged larvae were common in plankton samples containing hard, sharp animals such as pteropods, and that another common source was contamination from a previous haul owing to inadequate washing of the net. To investigate the damage caused by hard-bodied animals, counts were made of all pteropods occurring at Stations 66B and 71, where frigate mackerel mortality was 99·4 and 0·0%, respectively. The total number of pteropods was 22 for Station 66B, and 115 for Station 71, a reverse trend from what would be expected if pteropods damaged the larvae. Neither was damage proportional to the invertebrate plankton volumes obtained (Table 1), for no correlation was found when the plankton volumes were plotted against percentage mortality. It was concluded that the presence of other organisms in the catch had little to do with the condition of the larval frigate mackerel.

As stated earlier, the net was washed between tows so that few organisms could have persisted to contaminate later samples. Examination of the stations listed in Table 1 reveals that a catch showing a heavy mortality sometimes followed one of numerous normal fish, but that several stations were notably at variance with this. Thus Stations 66A and 66B were successive and had

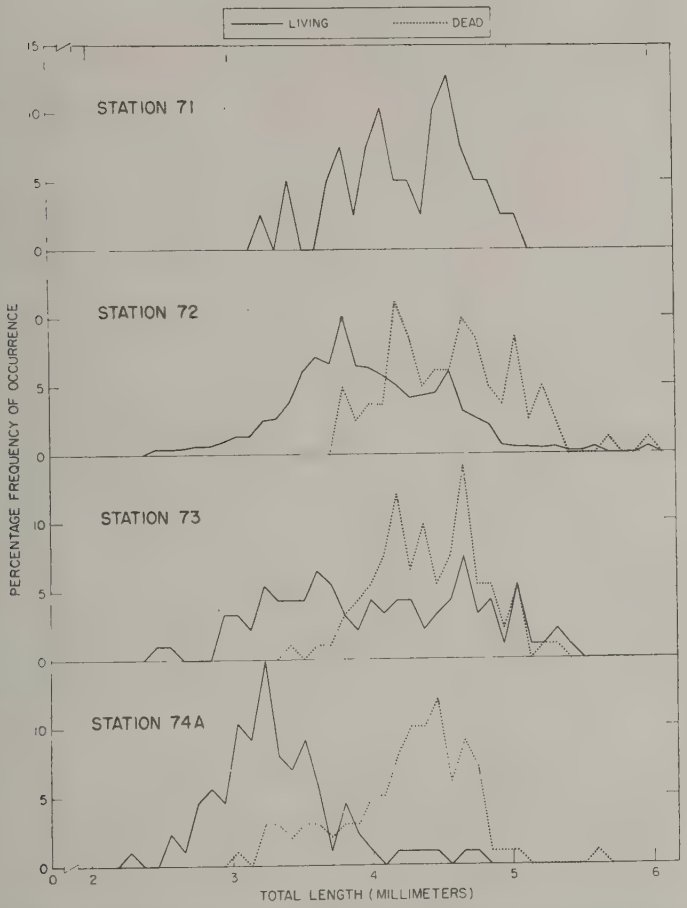

Figure 3. Length-frequency distribution of frigate mackerel at stations showing heavy mortality. Data derived from following numbers of fish: Station 71, 39 living; Station 72, 554 living, 81 dead; Station 73, 92 living, 92 dead; and Station 74A, 87 living, 99 dead.

equally high mortalities, as did Stations 73 and 74A, and Station 76 had an appreciable mortality, yet followed Station 75 where only 6 larvae were captured.

Another line of evidence tending to discredit contamination deals with the length-frequency distribution of the living and dead larvae. Here, total length was measured with the aid of an ocular micrometer, using the snout tip and the end of the longest caudal ray as reference points. Measurements were made to the nearest micrometer subdivision (0·095 mm) and subsequently converted to millimetres. Rather complete overlaps were found in length frequency for

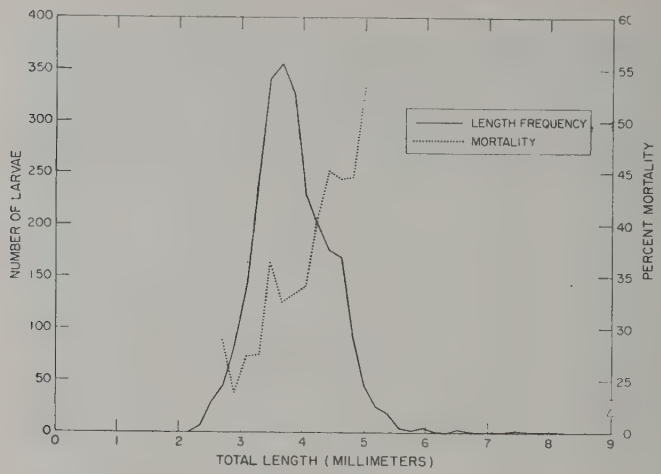

Figure 4. Length-frequency distribution of frigate mackerel, and percentage dead at various lengths. Length data derived from 2561 living and dead specimens; mortality figures based upon 2459 specimens.

Stations 64 through 69, but for Station 71 through 78 there was evidence that the dead fish were not from the same length populations as the living ones. Figure 3 shows that although the dead larvae taken at Station 72 could have been carry-overs from Station 71, there is little likelihood that those in Station 73 persisted from Station 72, or that those in Station 74 A were remnants from Station 73.

If the occurrence of the dead larvae was actually due to contamination then one would expect the mortality at a given length to be proportional to the number of fish of that length. That this is not so is shown by Figure 4, which depicts the mortality at each length category (a subsample was studied from Station 72, and mortality was not calculated for the smaller samples). Mortality is seen to increase with size, with fish about 5 mm in total length being most severely afflicted. As noted by STRASBURG (MS.), tuna larvae of 5 mm and larger are not often caught in plankton nets, probably because of their increased ability to avoid the net, so that their present capture may have been possible because they were dead.

A simple experiment was performed to determine if decomposing larval tuna would ultimately have the appearance of "dead" larvae. The plankton from several night surface tows was frozen after collection, thawed in the laboratory, and sorted in dishes placed in bowls of ice. Twenty-seven larval tuna (19 *Neothunnus macropterus*, 7 *Auxis* sp., and 1 *Katsuwonus pelamis*) were obtained, and these were examined and their appearance noted. Seven representative specimens were then preserved in formalin and the balance allowed to decompose in dishes of sea water over a period of nearly 47 hours at room temperatures of 23°–29°C. The decomposing specimens were re-examined at intervals and samples were preserved periodically. When all specimens had been preserved they were set aside for one week and then categorized as living or dead using

Table 2

Effects of decomposition upon appearance of larval tuna

Time sample preserved	Appearance of larvae (L = living, D = dead, L^1 and D^1 are intermediates)
10 min.....	4 L, 1 L^1, 1 D^1, 1 D
3 hr., 10 min.....	2 L, 2 D^1
6 hr., 45 min.....	2 D^1, 2 D
22 hr., 20 min.....	1 L^1, 3 D
30 hr., 55 min.....	1 L^1, 4 D*)
46 hr., 45 min.....	1 L, 2 D*)

*) Specimens badly deteriorated.

the criteria listed above. The effects of decomposition upon the appearance of these larvae are shown in Table 2 from which it is apparent that a "dead" appearance was generally acquired after 3–6 hours of decomposition. Some specimens, however, had a "living" aspect after 31 hours, and an unusually large fish (a 9·5 mm *Neothunnus macropterus*) appeared "living" after nearly 47 hours. Another larva appeared "dead" both at the start of the experiment and after a week in formalin.

Decomposition seems to be the agent responsible for the difference in appearance between the living and dead specimens. In this connexion it should be noted that decomposition in still water did not result in loss of the visceral mass, although it did cause a considerable loosening of that structure. Presumably the dead specimens taken at sea lost their viscera from agitation by waves or by the plankton net. It was also of interest that no experimental specimens bloated as decay progressed. This does not necessarily eliminate bloating-induced flotation as the mechanism responsible for dead larvae being caught at the surface, for apparently some fish decompose without rising to the surface (DENCE, 1956).

Causes of Death

In natural conditions an increase in the abundance of organisms is thought to be depressed by a system of checks and balances: predation, disease, competition, and the suitability of the physical environment. Predation can be excluded from the present case because it would have resulted in the recovery of no larvae or of larvae with some signs of natural mutilation. The agency involved instead appears to be generalized, for it afflicted a relatively wide size range of larvae, and was apparent over a distance of 12·5 miles and through a time interval of 29 hours.

Gross external examination of about 300 specimens (living and dead in about equal numbers) revealed no signs of disease, but it should be remembered that disease would not necessarily have external manifestations, and that slight symptoms could have been overlooked. No parasites were encountered on the gills, integument, or mouth surfaces, nor were any found internally.

About 500 living and dead larvae were examined for ingested food, with about 50 being dissected and the remainder viewed against a strong light which rendered them quite transparent. No food items were found in the digestive tract of any specimen, but in two cases the intestine was so bloated that the body wall bulged laterally, and when opened was found to be filled

with viscid white fluid. Those fish examined for the presence of food had been captured in the evening, at night, and at dawn, so that the lack of food in their stomachs may only mean that young frigate mackerel are daytime feeders. As can be seen from Table 1, no daytime samples were collected.

There is no way of determining if the mass death was caused by starvation. All specimens were past the "critical" period of yolk-sac absorption, and presumably had already begun feeding on planktonic food. Neither the type of food consumed nor its availability during the sampling period is known. There should be competition for food between individual frigate mackerel larvae and possibly also between them and various other members of the zooplankton. The invertebrate portion of the latter, however, was not over abundant in the samples collected, for the mean catch, 16·0 ml of plankton per 1000 m^3 of water strained was equal to, or less than, comparable Hawaiian plankton samples reported upon by KING and HIDA (1954, 1957). Thus if starvation were the cause of death it might have been induced by intra-specific competition or lack of a critical supply of the right sort of food.

POFI is continuing its studies of the Lanai area for several reasons, one of which concerns a water temperature discontinuity in the region from which the present samples came (Figure 1). In the discontinuity zone surface temperatures varied as much as 1·5°C in approximately one mile, and the surface was frequently characterized by floating terrestrial debris. As pointed out by MATSUMOTO (1958) and STRASBURG (MS.), larval frigate mackerel migrate to the surface at night, and would then be in a region of rapid temperature change at Lanai. Figure 1 also shows the discontinuity area to lie in the path of a current flowing south-easterly or easterly at a speed of about 0·5 knots.

It is to be noted that the upstream stations (Nos. 64, 65, 75–78) had frigate mackerel mortalities ranging only from 5·9% to 16·7%, whereas at certain downstream stations (Nos. 66A, 66B, 73–74B) mortality ranged from 23·9 to 99·4%. Although not true of all stations, it would seem that passage through the discontinuity area was directly related to mortality.

The location of the principal death site can be roughly calculated by means of the known decomposition rate and current speed. A 0·5 knot current would flow 1·5–3 miles in the 3–6 hours necessary for larvae to assume a "dead" appearance by decomposition. In the case of the stations showing the heaviest mortality (Nos. 66A and B), this could place the death site at or near the north-western edge of the discontinuity area. Current drift could also account for the appearance of large numbers of dead larvae downstream from the discontinuity area (Station 69). The lack of high mortality at such stations as 67, 68, and 72 is presently inexplicable.

Summary

1. The mass death of larval marine fish has been the subject of much speculation but has remained largely undocumented. The present paper deals with a series of Hawaiian plankton samples containing 3,493 larval frigate mackerel (*Auxis* sp.), large numbers of which were thought to be dead before capture.

2. The appearance of the dead larvae was markedly different from that of the living fish, and these differences could logically be associated with death prior to capture. Deterioration of the dead fish was probably not brought

about by contact with hard, sharp organisms, or by the fish remaining in the net between hauls. The length-frequency distributions and the percentage mortality of various length groups also discredited contamination of this sort. Fresh larvae allowed to decompose attained a "dead" appearance in from 3 to 6 hours.

3. The definitive cause of death could not be determined. There were no signs of predation, disease, or parasitism, but starvation could not be definitely excluded as a factor. It was tentatively hypothesized that the mass death was brought about by passage through an area having marked discontinuities in its surface water temperature.

References

Ahlstrom, E. H., 1954. "Distribution and abundance of egg and larval populations of the Pacific sardine". Fish. Bull., U.S., **56** (93): 83–140.

Dence, W. A., 1956. "Concretions of the alewife, *Pomolobus pseudoharengus* (Wilson), at Onondaga Lake, New York". Copeia, 1956: 155–58.

Fabre-Domergue, & Biétrix, Eugène, 1897. "La période critique post-larvaire des poissons marins". Bull. Mus. Hist. Nat. Paris, **3**: 57–58.

Hjort, J., 1914. "Fluctuations in the great fisheries of northern Europe viewed in the light of biological research". Rapp. Cons. Explor. Mer, **20**: 228 pp.

Hjort, J., 1926. "Fluctuations in the year classes of important food fishes". J. Cons. int. Explor. Mer, **1**: 5–38.

King, J. E., & Hida, T. S., 1954. "Variations in zooplankton abundance in Hawaiian waters, 1950–52". U.S. Fish Wildl. Serv., Spec. sci. Rep.-Fish., 118: 66 pp.

King, J. E., & Hida, T. S., 1957. "Zooplankton abundance in Hawaiian waters, 1953–54". U.S. Fish Wildl. Serv., Spec. sci. Rep.-Fish., 221: 23 pp.

Marr, J. C., 1956. "The 'critical period' in the early life history of marine fishes". J. Cons. int. Explor. Mer, **21**: 160–70.

Matsumoto, W. M., 1958. "Descriptions of larvae of four species of tuna and their distribution in central Pacific waters". Fish. Bull., U.S., **58** (128): 31–72.

Matsumoto, W. M. "Descriptions of *Euthynnus* and *Auxis* larvae taken by the 'Dana' and other Danish vessels, 1911–1938". MS.

Sette, O. E., 1943. "Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part I: Early life history, including the growth, drift, and mortality of the egg and larval populations". Fish. Bull., U.S., **50** (38): 149–237.

Strasburg, D. W. "Quantitative estimates of larval tuna abundance, with critical comments on sampling". MS.

4. Underwater Observations on the Behavior of Hawaiian Tuna

he oceanic skipjack or aku (*Katsuwonus pelamis*) bject to a considerable fishery in Hawaii, Japan, the continental United States. Because this tuna ught by chumming with live bait, and because is delicate and in short supply, the yield and it of the fishery are not as great as warranted world demands. The Pacific Oceanic Fishery In- igations is attempting to increase the efficiency, hence the yield and profit, of live-bait fishing studying skipjack behavior as it is related to ral fishing variables.

his study has been conducted from the research el "Charles H. Gilbert," which is equipped with underwater observation chamber. Through this mber movies were taken of skipjack behavior er normal and experimental fishing conditions. As pplement to the movies, comments of underwater surface observers were recorded, along with rded bell tones denoting catch rate. The ob- ation chamber had three months of use during 8, a poor year for the Hawaiian fishery, during ch observational techniques were developed while eriments were conducted. The experimental re- s, although encouraging, are only tentative.

everal experiments involved the effects of varia- s in chumming on skipjack behavior. When live dead nehu (*Stolephorus purpureus*) were chum- l alternately, the use of dead bait resulted in pjack decreasing their swimming speed and num- of surface dashes, and also in falling so far rn that fishing ceased. When the rate of chum- g was doubled, more nehu accumulated than ld be eaten by a small tuna school, again causing the tuna to fall behind. This did not apply to large schools, for these consumed the bait as rapidly as it was thrown. With the chumming rate halved, the tuna slowed their swimming and tended to scatter, no doubt as a result of an insufficient feeding stimulus. When water sprays were turned on and off at intervals, the "off" condition resulted in speed-slackening, reduction in the number of surface dashes, and deeper swimming, again reflecting inadequate feeding stimulation. Experiments in which nehu were replaced by threadfin shad (*Dorosoma petenensis*) showed that a too-conspicuous or too-active bait also resulted in a reduced catch.

Four other experiments dealt with rather extrinsic fishing variables. Noise produced by hammering on the ship's hull had no effects on behavior, nor did blood sprayed in the water or allowed to drain from the deck. Skipjack skin extracts thought to contain fright-producing purines or pterines similarly produced no visible response. When red food coloring was sprayed into the sea in dense concentrations, skipjack avoided any deeply stained masses of water, suggesting that perhaps they can be corralled by walls of sufficiently dark dye.

As more is learned about bait-skipjack interactions it becomes easier to select better bait species and lures and to modify existing fishing practices. The results of such tests as the dye experiments may lead to entirely new fishing methods.

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THE MORPHOLOGY AND LIFE-HISTORY OF THE DIGENETIC TREMATODE, ASYMPHYLODORA AMNICOLAE N. SP.; THE POSSIBLE SIGNIFICANCE OF PROGENESIS FOR THE PHYLOGENY OF THE DIGENEA

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Constitution of the Genus Asymphylodora

The genus *Asymphylodora* was erected by Looss (1899) to contain *Distoma perlatum* von Nordmann, 1832, a parasite from the intestine of *Cyprinus tinca,* as type species. Rudolphi (1809) had suggested and Looss agreed that the species is identical with *Fasciola tincae* Modeer, 1790, from the same host. In the genus *Asymphylodora,* Looss included *Distoma exspinosum* Hausmann, 1896 from the intestine of *Barbus fluviatilus* and *Distoma imitans* Mühling, 1898 from the intestine of *Abramis brama. Distoma ferruginosum* von Linstow, 1877 from the intestine of *Barbus fluviatilus,* was considered identical with *D. perlatum. Fasciola globiporum* Rudolphi, 1802 was listed as *Distoma globiporum* by Rudolphi (1809) who stated that it included *F. tincae* and several other inadequately described trematodes. Looss (1894) had given a detailed description of *D. perlatum* and although he admitted the identity of this species and *F. tincae,* he did not make the correct taxonomic revision when he erected the genus *Asymphylodora.* Lühe (1909) made the combination *Asymphylodora tincae* (Modeer, 1790); he recognized the validity of *Distoma ferruginosum,* which he included with the three species selected by Looss as members of the genus. *Distoma punctatum* Zeder, 1800 from the intestine of *Cyprinus barbus,* was listed as probably identical with *Asymphylodora ferruginosum.* All of these worms were from the intestine of cyprinid fishes of Europe.

Subsequently, members of the genus have been reported from various parts of the world. Isaichikov (1923) described specimens from cyprinid fishes of the Kuban River as *Asymphylodora tincae kubanicum,* and this form was re-described by Markewitsch (1951). Ozaki (1925) described *Asymphylodora macrostoma* from several species of fishes in Japan. Ivanitskii (1928) described *Asymphylodora dneproviana* from fishes in the Ukraine. Witenberg and Eckmann (1934) found worms in *Cyprinus carpio* in Syria which they identified as *A. tincae.* After noting the variability manifested by different individuals, they declared that all previously described species were identical and accordingly, all other specific names were reduced to synonymy with *A. tincae.* Markowski (1935) described *Asymphylodora demeli* from *Gobius minutus,* taken in the coastal waters of Poland. He

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accepted *A. macrostoma* as a valid species and asserted that the action of Witenberg and Eckmann was not justified, since it was based on evaluation of published descriptions rather than on comparison of specimens. Srivastava (1936) described *Asymphylodora indica* from the intestine of the fresh-water fish, *Ophiocephalus punctatus* in India. Yamaguti (1936) described *Asymphylodora diplorchis* from *Pseudogobio esocinus;* a species which according to Yamaguti (1958) had been described by Takeuti (1936) as *Steganoderma kamatsukae.* Yamaguti (1938) described *Asymphylodora japonica,* a species from *Cyprinus carpio* which had been identified by Nagano (1930) as *A. tincae.* In his report, Yamaguti (1938) stated that the asexual generations of this species occur in *Bulimus striatulus japonicus* and that the tailless cercariae encyst in the rediae. He emended the diagnosis of *A. macrostoma* and reported that larvae of this species encyst in the peribuccal tissue or gill arches of *Chaenogobius macrostomus, Gnathopogon elongatus caerulescens,* and *Cobitus biwae.* Serkova and Bykhovskii (1940) reported both redial and sexually mature stages of a species of *Asymphylodora* in *Bithynia tentaculata* collected near Leningrad, Russia. The worms were distinguished from previously described species by a tabular comparison of morphological features. Although the authors stated that only experimental studies under natural conditions, *i.e.,* the infection of fishes with young trematodes, will permit definite systematic disposition of the specimens, they were described provisionally as a new species, *Asymphylodora progenetica.*

Szidat (1943) considered the material of Witenberg and Eckmann to consist of two species, one of which he identified as *A. imitans* (Mühling, 1898) and the other he described as a new species, *Asymphylodora carpiae.* The latter species was regarded as identical with *A. tincae kubanicum* Isaichikov, 1923, and if this is true, *A. carpiae* is a synonym of *A. kubanicum.* Szidat distinguished between *A. tincae, A. exspinosa, A. ferruginosa, A. carpiae* and *A. demeli;* he attempted to assign species of *Asymphylodora* to particular hosts, *e.g., A. tincae* occurs apparently in a single host species, *T. tinca,* although other species are not so restricted. For the Asiatic species, *A. macrostoma* Ozaki, 1925 and *A. indica* Srivastava, 1936, Szidat erected a new genus, *Parasymphylodora,* which was suppressed by Skrjabin (1955). Szidat also erected a new genus, *Paleorchis,* for the species with two testes, *i.e., A. diplorchis* Yamaguti, 1936 and two species which he described as new, *viz., P. incognitus* from the intestine of *Leuciscus rutilus* and *P. unicus* from the intestine of *Blicca björkna.* The three genera, *Asymphylodora, Parasymphylodora* and *Paleorchis* were included in a new subfamily, Asymphylodorinae. This subfamily was assigned to the family Lecithodendriidae Odhner, 1910, together with the subfamilies Lecithodendriinae Looss, 1902; Pleurogenetinae Looss, 1899; Haploporinae Looss, 1902; Monorchinae Odhner, 1911; Proctotreminae Odhner, 1911; and Zoogoninae Odhner, 1911. Szidat (1943) stated (p. 70), "Unter Hinweis auf schon früher (1926) erhobene Befunde wird dargelegt, dass die genannten Trematodengruppen lediglich als Unterfamilien der grossen Trematodenfamilie Lecithodendriidae aufzufassen sind, womit ein neuer Beweis für die von dem Autor vertretene Auffassung einer *Parallelentwicklung der Trematoden mit ihren Wirten im Laufe der Phylogenie* erbracht wird und die von W. EICHLER aufgestellten Korrelationsregeln in der Stammesentwicklung von Wirten und Parasiten, die sog. FAHRENHOLZsche und die SZIDATsche Regel erneut bestätigt werden konnten."

Other species, subsequently described as new, include *Asymphylodora atherinopsidis* from the "jack smelt" *Atherinopsis californiensis* taken at Stinson's Beach, California by Annereaux (1947); *Asymphylodora markewitschi* from *Carassius carassius* taken in Russia by Kulakowskaja (1947); *Asymphylodora pontica* from *Neogobius melanostomus* taken in Odessa Bay by Tschernyschenko (1949); *Asymphylodora kedarai* from *Punctius sophora* taken in India by Srivastava (1951); *Asymphylodora macracetabulum* from *Misgurnus anguillicaudatus* taken in Russia by Belous (1954); and *Asymphylodora dollfusi*, a progenetic metacercaria from *Bithynia leachi* taken in the north of France by Biguet, Deblock and Capron (1956). It should be noted that Markewitsch (1951) predicated the identity of *A. dneproviana* and *A. imitans* (Mühling, 1898) and Skrjabin (1955; p. 408) confirmed the opinion. Certain of the species of *Asymphylodora* are described only briefly and others, *e.g., A. atherinopsidis,* which was described from a single worm, are based on a small number of specimens. Which of the twenty named species are actually valid remains to be determined.

Life History and Larval Stages

The life-cycle of members of the genus *Asymphylodora* has been the subject of much controversy. It presents many interesting features and has been under investigation for more than a century. Von Baer (1827) described *Cercaria paludinae impurae* and the species described by de Filippi (1854) from the same host under the name *Distoma paludinae impurae* may be identical with it. It is impossible, however, to make positive determinations on the basis of those early accounts. In the species described as *D. paludinae impurae,* de Filippi reported the finding of a large number of rediae, which produced the distomes directly. These rediae had very short, dilated intestines and no lateral processes of the body wall. The young rediae were motile and moved in a lumbricid manner, while the older ones were inert and contained active distomes, about 0.40 mm. in length, which strongly resembled *Distoma luteum* von Baer, 1826 from *Paludina vivipara.* In this paper, de Filippi reported daughter rediae in a mother generation. He predicated that the production of distomes in a redia is not to be interpreted as an example of simplified development. He stated that these distomes differ from cercariae only in the absence of a tail; he observed cystogenous cells under the body wall, but noted that encystment occurs only outside of the body of the *Paludina.* In a footnote, he described distomes found in *Paludina vivipara* from the Lac de Varése, which measured up to 2 mm. in length and in which the sexual organs were present as rudiments. The worms had no fixed location, but moved about and were found on the mantle. De Filippi expressed the belief that they had come from some other animal and had merely taken refuge in *P. vivipara.* He stated that they were quite distinct from the cercariae which are normal parasites of these mollusks. This large species may be identical with the one from *P. vivipara* described by Swammerdam in the Biblia Naturae (Boerhaave edit. 1752, p. 75, Table IX, Figs. 7, 8) and by von Baer (1826) as *Distoma luteum.*

In a second mémoire, de Filippi (1855) described other distomes from mollusks. These observations demonstrated that tailless cercariae occur in the life-cycles of very different trematodes; that they may be produced in either sporocysts or rediae, and that they may be found in snails without the antecedent generation in

which they originated. The absence of a tail, then, is no evidence of genetic relationship.

In a third mémoire, de Filippi (1857) reported that *Distoma paludinae impurae* occurs in two forms which he designated *armatum* and *inerme,* respectively, the latter of which was recognized as the larval stage of *Distoma perlatum* von Nordmann. As noted, Looss (1894) gave a detailed description of *D. perlatum.* He identified the two forms *Distoma paludinae impurae armatum* and *Distoma paludinae impurae inerme* as developmental stages of *D. perlatum* and reported that the cercariae develop in *Bithynia tentaculata.* These two larvae had been transferred to *Cercariaeum* by Diesing (1858) and Szidat (1943) suggested that Looss had found only *D. paludinae impurae armatum.* According to Looss, the cercariae may leave the snail in which they were produced and they may encyst either in the same snail or in others in which no redial stages are present. According to Looss, Wagener (1857) had observed and "hübsch gebildet" this species, but had assigned it erroneously to *Cercaria lymnaei auricularis* de Filippi, 1854. Lühe (1909) accepted the statement of Looss that *Cercariaeum paludinae impurae* from *Bithynia tentaculata* is a larval stage of *Asymphylodora tincae.* He wrote (p. 93) "Die Cercarie, *Cercariaeum paludinae impurae* (Fil.), (schwanzlos, 0.4 mm. lang) entwickelt sich in *Bithynia tentaculata* (L.) in Redien, deren dicker, sackförmiger Darm ungefähr bis zur Grenze der beiden ersten Drittel der Körperlänge reicht (vgl. Fig. 186). Ein Hilfswirt dürfte bei der Schwanzlosigkeit der Cercarie fehlen." In this work Lühe erected the group, Cercariae, with two genera, *Cercariaeum* and *Leucochloridium,* to contain tailless larvae. Members of *Cercariaeum* develop in rediae or unbranched sporocysts and do not encyst. In it he included *C. limnaei obscuri* Ercolani, 1881 and *C. planorbis carinati* de Filippi, 1857 which develop in rediae, together with *C. lymnaei auricularis* de Filippi, 1854 and *C. ancyli lacustris* Diesing, 1855 which develop in sporocysts. Members of *Leucochloridium* develop in branched sporocysts. Sewell (1922) divided the Cercariaea into three sections; *Leucochloridium* was retained but *Cercariaeum* was split into two parts, the "Mutabile Group" which develop in rediae and was named for *C. mutabile* Cort, 1918 and the "Helicis Group" which develop in unbranched sporocysts and was named for *C. helicis* Meckel, 1846. Meanwhile, Fuhrmann found redial and cercarial stages in *Limnea auricularis* var. *ampla* taken in the region of Neuchâtel, Switzerland which he (1916) described as *Cercariaeum squamosum.* The rediae were 2.2 to 3.5 mm. long and the cercariae 0.36 mm. long. The cercariae were covered, except for the ventral area between the suckers, with cuticular scales which were similar to those of species of *Asymphylodora.* Fuhrmann postulated that *C. squamosum,* rather than *C. paludinae impurae* as stated by Lühe (1909), is a larval stage of *A. tincae.*

Dubois (1929) described the redial and cercarial stages of *Cercariaeum squamosum* and reported the species from *Lymnaea limosa, Lymnaea stagnalis* and *Planorbis carinatus.* The rediae were described as simple, saccate structures and Dubois noted such variability in dimensions of body and suckers of cercariae from different individuals of the same species, that he regarded the tailless larvae from all the above named snails as specifically identical. In the Cercariaea, he recognized five groups:

1. Groupe Mutabile. These larvae develop in rediae; they have two testes; the excretory vesicle is tubular and flexible; the flame-cell formula is 2 [(4 + 4 + 4 + 4) + (4 + 4 + 4 + 4)].

2. Groupe Helveticum. These larvae develop in rediae; they have two testes; the excretory vesicle is tubular and flexible; the flame-cell formula is 2 [(3 + 3 + 3) + (3 + 3 + 3)].

3. Groupe Squamosum. These larvae develop in rediae; they have a single testis; the excretory vesicle is small, pyriform or rounded; the flame-cell formula is 2 [(4 + 4 + 4 + 4) + (4 + 4 + 4 + 4)].

4. Groupe Helicis. These larvae develop in sporocysts; number of testes and form of excretory system uncertain.

5. Groupe Leucochloridium. These larvae develop in sporocysts; number of testes and form of excretory system uncertain.

Dubois' observations upheld the morphological agreement, noted by Fuhrmann, between *C. squamosum* and *A. tincae* and accordingly he recognized the identity of the two forms. In the Groupe Squamosum he included *C. paludinae impurae inerme* together with *C. planorbis carinati* and *C. limnaei obscuri*. According to Dubois, *C. paludinae impurae armatum* has a small stylet, two testes, a tubular excretory vesicle, and since it has a flame-cell formula of 2 [(3 + 3 + 3) + (3 + 3 + 3)], it was included in the Groupe Helveticum.

Wesenberg-Lund (1934) described tailless larvae from *Bithynia tentaculata* which he identified as *C. paludinae impurae*. In general morphology these larvae agreed with those from the same host which were described by Dubois (1929) as *Cercariaeum helveticum* I and which were included together with *C. paludinae impurae armatum* to form the Groupe Helveticum. Wesenberg-Lund did not observe a stylet, but otherwise the two forms were very similar. Redial stages and encysted metacercariae were found in the same snail. The cyst walls were thin and membranous. Wesenberg-Lund confirmed the observations of Wunder (1924) that the larvae emerge from the spiracle of the infected snail, pass over the head and proceed along the tentacles, which may appear fluffy in their entire length, with as many as fifty worms on each, or the larvae may accumulate at the tips. The cercariae are always attached by their ventral suckers, with the anterior and posterior portions elevated. If the tentacles come in contact with other snails, the larvae may transfer to the new hosts where they later encyst, usually near the heart or rectum. The author agreed with Dubois that the *inerme* and *armatum* forms of de Filippi are distinct species, but no attempt was made to relate either of them to an adult form. Wesenberg-Lund identified other tailless larvae from *Lymnaea auricularia* as *Cercariaeum lymnaei auricularis* de Filippi, 1854 and his description of these specimens agrees closely with that of *C. squamosum* from the same host as given by Fuhrmann (1916) and Dubois (1929). The two forms are obviously related, but their relation to *A. tincae* is undetermined.

As noted, Serkova and Bykhovskii (1940) described *Asymphylodora progenetica* from the liver and other organs of *Bithynia tentaculata* in Russia. They reported that more than 50 per cent of the mollusks were infected, each with one to seven worms; about 60 per cent of the worms were juveniles, the others sexually mature with eggs in the uterus. None of these worms was encysted. In addition to the juvenile and mature worms, some 15 to 20 per cent of the snails harbored

rediae which were presumed to belong to the same species. Each redia contained from one to eight tailless cercariae. Three sets of experiments were performed. In the first, uninfected specimens of *B. tentaculata* were placed in aquaria with infected ones. At the end of one month, both juvenile and gravid worms were found in the previously uninfected snails. The worms were always free; none was encysted. No rediae were found in the previously uninfected individuals. There was no statement concerning the number of snails used in the experiment nor of the criteria used to determine whether or not the snails were infected. In a second experiment, fifteen uninfected specimens of *B. tentaculata* were placed in each of three aquaria and eggs of *A. progenetica* were added. At the end of twenty days the following results were obtained: in Aquarium I, there was one snail which contained an embryonic mass, presumed to be of *A. progenetica,* and the others were not infected; in Aquarium II, one snail contained eight mature specimens of *A. progenetica* with eggs in their uteri and four dead worms, while the other snails were not infected; in Aquarium III, none of the snails was infected. From these results, the authors concluded that the life-cycle of *A. progenetica* can be completed in *B. tentaculata,* and that the development from eggs to mature adults can take place in twenty days. In the third experiment, pieces of *B. tentaculata* were fed to cyprinid minnows, *Rutilus rutilus* and *Carassius carassius.* In *R. rutilis,* the worms persisted for six days but were absent after fifteen days; in *C. carassius,* the worms were present after twenty-four hours, but not at the end of three days. The experiments reported by Serkova and Bykhovskii are not at all convincing. In the absence of information concerning controls, the results can not be evaluated properly. However, the belief that *B. tentaculata* harbors a single species, and that the rediae and cercariae were larval stages of the species whose juvenile and sexually mature stages were described as *A. progenetica,* was not adequately supported. The results of the attempt to infect *B. tentaculata* discredit the stated conclusions. The failure to obtain rediae suggests the absence of experimental infection. The finding of an embryonic mass in one snail is equivocal, and the snail with eight gravid worms was certainly infected at the time of exposure.

Szidat (1943) confirmed earlier observations of Dubois (1929) and Wesenberg-Lund (1934). He reported that the adult stage of *C. paludinae impurae armatum* occurs in *Leuciscus rutilus* and for it he erected a new genus, *Paleorchis.* He noted that the first three groups of Dubois are closely related, whereas the fourth and fifth groups, which develop in terrestrial snails, are members of a different family, Harmostomidae (= Brachylaemidae). Szidat declared that the larvae of *Asymphylodora* certainly belong in the Squamosum group of Dubois. He recognized *C. limnaei auricularis* de Filippi, 1854 and *C. squamosum* Fuhrmann, 1916 as distinct species, and the former was identified as the larva of *A. tincae.* Provisionally, the latter species was referred to *A. imitans* (Mühling, 1898). Szidat considered the probability that *C. planorbis carinati* de Filippi, 1857; *C. limnaei obscuri* Ercolani, 1881; and *C. squamosum* Fuhrmann, 1916 are identical with *C. paludinae impurae inerme* de Filippi, 1854.

The five larval groups of Dubois have now been correlated with their adult stages. Wallace (1941) reported that *C. mutabile* Cort, 1918 is the larva of a species of *Triganodistomum* Simer, 1929. The Helveticum group contains the lar-

vae with stylets, two testes, which according to Wunder (1924) leave their primary hosts and encyst in secondary hosts. They were identified by Szidat (1943) as developmental stages of species of *Paleorchis*. Members of the Squamosum group are larvae of *Asymphylodora*. Thomas (1959) transferred *Triganodistomum* to the Monorchiidae and thus, members of the three groups belong in the family Monorchiidae or in the subfamily Monorchiinae if the proposal of Szidat is accepted and the monorchids are regarded as a subfamily in the expanded family Lecithodendriidae.

The identity of corresponding stages of species in the genus *Asymphylodora* is yet undetermined. Deblock, Capron and Biguet (1957) reported specimens of *Asymphylodora* from the intestine of *T. tinca* taken in the north of France. These worms differed from descriptions of *A. tincae* as given by earlier authors, including Szidat (1943) who associated *A. tincae* exclusively with *A. tinca*. The worms described by the French authors were differentiated from previous descriptions of *A. tincae* on the basis of three features, *viz.*, the presence of a short common sperm duct before the seminal vesicle, the extension of ventrolateral pores to converge and meet behind the acetabulum, and the absence of spines on the ventral area between the suckers. The worms were designated as a new variety, *Asymphylodora tincae mediaglabra*. The question was raised if the larval form of the classically described form of *A. tincae* is not *C. paludinae impurae inerme* as postulated originally by de Filippi (1857).

Experiments

Stunkard (1955) reported the finding in the summer of 1954 of both juvenile and sexually mature trematodes in the fresh-water pectinibranchiate snail, *Amnicola limosa*, collected from ponds in the vicinity of Woods Hole, Massachusetts. About one-fourth of the fully grown snails were infected. From one to nine unencysted worms, identified as members of the genus *Asymphylodora*, were found in an infected snail. As a rule, when several specimens were present only one or two contained eggs, but as many as five gravid worms were found in a single snail. The presence of worms of different sizes and degrees of development, from very young to gravid specimens, indicated successive repeated infections. When removed to a glass slide, juvenile specimens frequently encysted but encystment of sexually mature worms was not observed. The cyst walls were thin and membranous. No sporocyst or redial stages were found at the time and it appeared that the asexual generations of the worms occur in some species other than *A. limosa*.

The worms were found, but only rarely and in small numbers, in the intestines of fishes from the same ponds. They were taken from yellow perch (*Perca flavescens*), fresh-water killifish (*Fundulus diaphanus*), small-mouth bass (*Micropterus dolomieu*) and bluegill sunfish (*Lepomis macrochirus*). Whether the fishes obtained the worms by eating snails or by eating small fishes which had eaten snails is unknown. Trematodes from ingested fishes may persist for some time in the intestines of predatory animals and parasites of the prey may easily be mistaken for parasites of the predator. The eggs of the parasite contained miracidia and those in worms from snails were identical in appearance with those in worms taken from the intestine of fishes. The ponds had been stocked at various times by the Division of Fisheries and Game of the State of Massachusetts.

Subsequently, redial and cercarial stages of this parasite have been found in natural infections of *A. limosa;* from one to three per cent of the snails in different collections. In addition, sporocysts and rediae have been recovered from experimentally infected, laboratory-reared snails. *Amnicola limosa* is a dioecious species; eggs are laid singly and young specimens are present in numbers in laboratory cultures. The snails are temperamental feeders, living principally on diatoms, and it is difficult to maintain them for long periods, especially when infected. Cultures of diatoms were provided by Dr. Luigi Provasoli of the Haskins Laboratories in New York, for which grateful acknowledgment is made.

Eggs passed by worms taken from snails were maintained in pond water for one to six days to insure embryonation and then fed to young, laboratory-reared *A. limosa.* Each snail was placed in a stender dish, 5 cm. in diameter, together with a number of eggs. The next day the snail was removed to a larger container for more favorable conditions. Dissection of these snails, beginning after one week, disclosed sporocysts and rediae indistinguishable from those of natural infections. Whether or not there is a daughter sporocyst generation was not determined.

Cercariae removed from the tentacles of a snail were placed in a small stender dish, 3 cm. in diameter, with a small uninfected, laboratory-raised *A. amnicola.* The following day they had disappeared and the snail was dissected. About one-half of the cercariae had encysted. This finding is difficult to interpret since very few cysts have been found in snails from ponds, although often one-third or more of them contained unencysted juvenile or gravid worms.

If a snail harbors the asexual generations, the tailless cercariae emerge and migrate to the tentacles where they cling in the manner described by Wunder (1924) and Wesenberg-Lund (1934). The worms adhere by the acetabulum, with the ends of the body extended and elevated. The larvae may remain attached at any location on the tentacles and sometimes accumulate near the tips. When many cercariae are attached, the tentacles may manifest a feathery appearance. If such an infected snail makes contact with an uninfected one, the cercariae may transfer to the tentacles or body of the uninfected specimen. In the new host, they often encyst in thin membranous envelopes that are not reinforced with a cyst wall deposited by the host. If cercariae are removed from tentacles and placed in a small stender with the same snail, they soon regain their position on the tentacles. If placed in a dish with an uninfected snail, they attach and may migrate to the tentacles, but they do not remain there; instead, they move about and in most instances enter the tissues. In snails that do not harbor asexual generations, the worms may be recently encysted, they may be unencysted juveniles of older infections, or unencysted gravid specimens. Such worms often contain hundreds of eggs and those in the terminal part of the uterus contain fully formed miracidia. No rediae have been found in snails that harbored juvenile or sexually mature worms, and no juvenile or mature worms in snails that harbored the asexual generations. It appears that the cercariae leave an infected snail and enter only snails that do not harbor asexual infections. Since several worms, often two to four of them gravid, may occur in a snail, the presence of one worm does not confer complete immunity and inhibit the entrance of others. Juvenile worms may encyst or remain unencysted since such specimens retain their cystoge-

FIGURES 1–7.

nous glands for some time and can encyst if removed from their hosts. The worms grow in their cysts since they increase somewhat in size, but major growth and maturity take place in unencysted specimens. It appears if the metacercariae encyst, that later they emerge because all older and gravid worms were free in the tissues of the snail.

Descriptions

The adult (Figs. 5, 7)

The worms are fusiform, wider near the middle and narrower at the ends. The preacetabular portion of the body is almost cylindrical and since the acetabulum is large and often protruding, fixed and stained specimens are frequently oriented on the side (Figs. 2, 5), with the dorsoventral measurement greater than the width. In cercarial and juvenile specimens the acetabulum is in the posterior half of the body but with sexual maturity and the accumulation of eggs in the uterus, the acetabulum is shifted relatively farther forward and may come to lie in the anterior half of the body. The worms continue to grow after sexual maturity is attained. Specimens from fishes as a rule are somewhat larger than those from snails. Gravid worms from snails when fixed, stained and mounted measure from 0.28 to 0.58 mm. in length and 0.14 to 0.24 mm. in width; corresponding measurements of worms from fishes are 0.40 to 0.71 mm. and 0.18 to 0.25 mm. The acetabulum measures 0.09 to 0.13 mm. in diameter.

The anterior end of the body in juvenile specimens bears a number of protrusible papillae, each provided with a seta, and these papillae are sometimes visible in gravid specimens. Other papillae are present at the rim of the acetabulum. The cuticula has a characteristic spination. Over much of the anterior half of the body the spines are slender, sharp, distinctly separated and 0.006 to 0.008 mm. long. On the ventral side, the median area between the suckers lacks spines and on the dorsal side in the corresponding area the spines are reduced in size and number. On the posterior part of the body the spines are broader, more scale-like in appearance and less numerous. Around the openings of the suckers there are six to seven rows of very small spines. They are closely set, triangular in shape and manifest a serrate appearance. From these areas, the spines gradually change in size and shape to conform with the aciculate and scale-like types on the adjacent areas. The parenchyma of the body, especially in the anterior portion, contains a large number of glandular cells; the ducts of many of them lead forward to open near the anterior end of the body. Other glandular cells open

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The figures, except that of the egg, were made from fixed and stained specimens.

[1] Figure 1. Metacercaria, removed from cyst; much flattened for study of the excretory system; ventral view, 0.43 mm. long.

Figure 2. Cercaria, removed from a redia; lateral view; 0.19 mm. long.

Figure 3. Redia; natural infection; a large specimen; 0.9 mm. long.

Figure 4. Redia; one of four, from experimental infection of a laboratory-raised snail; 0.19 mm. long.

Figure 5. Adult; lateral view; one of the largest specimens; from *Perca flavescens;* 0.70 mm. long.

Figure 6. Egg, extruded from a gravid worm after removal from a snail, examined in water; 0.027 mm. long.

Figure 7. Adult; ventral view; somewhat compressed; from *Amnicola limosa;* 0.49 mm. long.

on the ventral side, especially in the area between the suckers, but rows of pores as reported by Looss (1894) and by Deblock, Capron and Biguet (1957) were not apparent. Such a linear arrangement would probably be produced only when that portion of the body is extended, otherwise the alignment would be disturbed.

The oral sucker is 0.06 to 0.095 mm. in diameter. The mouth is subterminal; there is a short prepharynx and the pharynx measures 0.036 to 0.044 mm. in diameter. The esophagus is long, the length dependent on the degree of extension of the preacetabular portion of the body, and the bifurcation of the digestive tract is immediately in front of the acetabulum. The ceca extend posteriad on the dorsal side of the body and end blindly at the level of the posterior part of the testis. The worms in the snails feed on tissues, as the digestive ceca contained cells, nuclei and cellular debris that could have come only from the molluscan host.

The excretory pore is terminal; the vesicle is small, lined with high epithelial cells. The collecting ducts pass forward to the level of the pharynx where they turn backward, and shortly anterior to the acetabulum they divide into anterior and posterior branches. Each branch has four groups of four flame-cells and the formula is $2\ [(4+4+4+4)+(4+4+4+4)]$, which is characteristic for members of the Squamosum group of cercariae. These observations were made on juvenile specimens (Fig. 1) since in gravid worms the development of the reproductive organs and the accumulation of eggs in the uterus make it impossible to work out the flame-cell pattern.

There is a single testis although the presence of two sperm ducts indicates its dual nature. It is median, located near the posterior end of juvenile and young specimens. As the body becomes congested with eggs in the uterine coils, the testis is shifted more dorsad and forward; indeed the post-testicular region may be as long as the testis. The testis is oval, 0.08 to 0.13 mm. in length and 0.06 to 0.10 mm. in width. Two sperm ducts pass forward, one from each side of the testis. In certain specimens they unite immediately before the cirrus sac and in others they unite to form a short duct which leads to the cirrus sac. Within the sac, the duct expands to form a twisted or coiled seminal vesicle which may appear bipartite or tripartite. The seminal vesicle is succeeded by a short prostatic region and then the ejaculatory duct, lined with spines, leads to the common genital pore. The prostatic cells occupy most of the space in the cirrus sac in front of the seminal vesicle. The ejaculatory duct may be everted to form the protruded cirrus. The cirrus sac extends in a curved course from the level of the anterior end of the ovary to the genital pore, situated on the left side at the acetabular level.

The ovary is dextral, immediately anterior to the testis, or the two may overlap. It is oval, somewhat smaller than the testis, and measures 0.06 to 0.11 mm. in length and 0.05 to 0.09 mm. in width. The oviduct arises from a ventral prominence near the posterior end of the ovary and makes a median posterior bend, after which it expands into a small seminal receptacle from which Laurer's canal extends to the dorsal surface of the body; it then receives the common vitelline duct and expands to form the ootype, enclosed in the cells of Mehlis' gland. The initial part of the uterus contains spermatozoa. From the ootype, in young specimens, the uterus passes forward to the level of the anterior end of the acetabulum,

then back on the right side to the posterior end of the body and forward on the left side to join the metraterm. But in older, fully gravid individuals, the anterior loop extends forward to the pharynx, coils about in the preacetabular region, filling much of the body between the suckers, and the posterior loop also winds about filling and expanding this portion of the body. In general, the uterine coils lie below the gonads and vitellaria and their course can be followed by the color of the eggs which are light in the initial part of the uterus and become darker as they proceed. The metraterm is a thicker-walled, terminal part of the uterus, about one-third as long as the cirrus sac, and the lumen is lined with cuticula which bears spines, similar to those which line the ejaculatory duct. There are nine vitelline follicles on each side of the body; typically there are five in a median, longitudinal row and four in a lateral row but contraction of the body muscles and pressure from other organs may disturb this arrangement. The follicles measure 0.033 to 0.043 mm. in diameter and are situated in the region between the acetabulum and the posterior end of the testis. Large collecting ducts from the follicles of each side pass mediad on the dorsal side of the body to form a vitelline receptacle, from which the common duct leads anteriad and ventrad to join the oviduct. The eggs (Fig. 6) are ovate, slightly narrower at the opercular end and somewhat flattened on one side. There is a thickened projection or knob asymmetrically situated near the antopercular end of the egg. The young eggs are almost colorless and the cells within stain readily; mature eggs have thick, yellow shells and contain a miracidium. The eggs measure 0.025 to 0.029 mm. in length and 0.013 to 0.016 mm. in width.

The sporocyst

No sporocysts of natural infection were found. In a snail exposed on July 3 and sacrificed on July 12, there was a sporocyst which measured 0.07 by 0.52 mm. It contained only germinal cells. Another sporocyst found on July 25 in a snail exposed on July 10 was slightly larger and in addition to germinal cells it contained three small germinal masses, embryos of the next generation.

The redia (Figs. 3, 4)

The rediae are simple sausage-shaped structures, without collar or feet, typically cylindrical although often attenuated at one or both ends. The body wall contains both circular and longitudinal muscles, so the rediae are slender when elongated and plump when retracted. In size they measure up to 1.00 mm. in length and 0.2 mm. in width, although most of them are only about one-half this size. There is a birth-pore situated near the pharynx. The pharynx has a diameter of 0.035 to 0.040 mm.; the gut has a short neck-like portion and the intestine is saccate. In young, small rediae it may extend one-third of the length of the body but it does not increase appreciably in size, and in older, mature specimens it occupies only a small fraction of the body cavity. Figure 4 shows one of four rediae found in a laboratory-raised snail exposed on July 14, 1955, and dissected on the following September 7th. The rediae were all approximately the same size. The one shown in the figure measures 0.19 by 0.13 mm. and the pharynx is 0.030 mm. in diameter.

The cercaria (Fig. 2)

The cercariae grow to large size in the rediae. Specimens removed from rediae or taken from tentacles of snails measure from 0.16 to 0.32 mm. in length and 0.06 to 0.12 mm. in width. The oral sucker is 0.05 to 0.06 mm.; the acetabulum 0.06 to 0.07 mm.; and the pharynx 0.033 to 0.035 mm. in diameter. The reproductive organs are represented by a lobed mass of germinal cells situated dorsal and perhaps slightly posterior to the acetabulum. The excretory system was not fully worked out in cercariae, but apparently it is completed in the cercarial stage and so far as determined, is identical with that found in juvenile worms.

The metacercaria (Fig. 1)

Cercariae from the tentacles of a snail were placed in a small stender dish with a small, laboratory-reared *A. limosa*. The following day they had disappeared and the snail was dissected. About one-half of the cercariae had encysted. The cysts measured 0.19 to 0.22 mm. in diameter; they were very thin-walled and ruptured easily under pressure of a coverglass. A few encysted specimens have been found in naturally infected snails, but almost all the metacercariae from natural infections were unencysted. On a few occasions, juveniles removed from naturally infected *A. limosa* encysted when removed to a slide for observation. The specimen shown in Figure 1 was removed from a cyst; it is hardly more than a cercaria since it had been removed from the tentacle of a snail the day before. It was very much flattened to study the excretory system. The unencysted metacercariae feed and grow; some of the juveniles were as large as worms with eggs in the uterus. Large numbers of dead, gravid worms have been found in naturally infected snails.

Except for the single specimen from the marine silverside, *Atherinopsis californiensis*, described by Annereaux (1947) as *Asymphylodora atherinopsidis* n. sp., the genus *Asymphylodora* has not been reported previously from North America. Mature specimens from *A. limosa* are smaller than those of either *A. progenetica* or *A. dollfusi*. The suckers are smaller, but the gonads and eggs are larger. There are differences also in the number of vitelline follicles. Description of the several stages of the species found in *A. limosa* taken from ponds in the Woods Hole region indicates that the specimens can not be assigned to any known species, and they are described as a new species, *Asymphylodora amnicolae*.

Discussion

In the paper describing *Distoma paludinae impurae*, de Filippi (1854) made the first distinction between sporocysts and rediae. He noted that *Redia gracilis*, described by him (1837), was a developmental stage of an amphistome and that similar stages occur in other species. Accordingly, he declared that the term, Redia, is not a generic name but like Cercaria O. F. Müller, 1773, is merely a stage in the life-cycle of certain trematodes. He characterized sporocysts as simple, membranous sacs without internal organization, whereas rediae are provided with a mouth, muscular pharynx, and intestine. In certain species, the body of the redia may form temporary lateral processes. It was common knowledge that cercariae could be produced in either sporocysts or rediae and de Filippi reported

daughter rediae in a mother generation. The term *"méta-cercaire"* was proposed by Dollfus (1913) to designate the immediate postcercarial stage, whether encysted or not, although in later publications he wrote the name as a single word, métacercaire. The designation of this stage is a contribution which facilitates description and discussion of life-cycles among digenetic trematodes.

Sexual maturity and production of eggs by metacercariae had been known since the report by von Siebold (1835) of eggs emerging from metacercariae found in *Astacus astacus*. For sexual maturity of animals which had not yet attained adult condition, Giard (1887) proposed the term "progenèse" and Dollfus (1924) applied the designation to gravid metacercariae of digenetic trematodes. Sinitsin (1905) reported sexually mature specimens of *Pleurogenes medians* encysted in aquatic larvae of *Agrion* sp. taken in the vicinity of Warsaw. Joyeux (1923) found gravid specimens of *Ratzia parva* in cysts from *Rana esculenta* in North Africa and obtained swimming miracidia from the eggs. Mathias (1924) obtained adults of *Pleurogenes medians* in *Rana temporaria* and *Hyla arborea* after feeding encysted metacercariae from *Gammarus pulex*. Many of the metacercariae contained eggs.

Dollfus (1927) described progenetic metacercariae of *Dinurus tornatus* (Rudolphi, 1819) and wrote (p. 55), "La découverte de cette forme permet cependant de se poser une fois de plus la question de savoir s'il peut exister, chez les trématodes digénétiques, des cycles abrégés par suppression de l'hôte définitif; l'on n'a pas, toutefois, démontré que les oeufs formés par les métacercaires progénétiques soient susceptibles de donner des miracidia infectants pour le mollusque premier hôte. Il semble que l'expérience seule pourra fournir la solution de ce problème si intéressant pour la biologie générale." Fuhrmann (1928) reported progenetic metacercariae of *Ratzia parva* in cysts from the muscles of *Rana temporaria,* and Dollfus (1929) again raised the question, "Existe-t-il des cycles évolutifs abrégés chez les trématodes digénétiques? Le cas de *Ratzia parva* (Stossich, 1904)." He stated (p. 203), "La métacercaire est progénétique, elle donne des oeufs contenant un miracidium. L'on n'a pas encore pu établir si ce miracidium renferme des éléments germinaux et est infestant pour le mollusque premier hôte, mais le seul fait que ce miracidium existe et nage activement dans l'eau après éclosion de l'oeuf permet de se demander s'il n'existerait pas, chez *Ratzia* outre un cycle évolutif complet comprenant un adult vrai dans l'hôte définitif, un cycle abrégé dans lequel la métacercaire jouerait le rôle d'adult et le deuxieme hôte intermédiare le rôle d'hôte définitif." Reproduction in progenetic metacercariae of *R. parva* was discussed by Joyeux, Noyer and Baer (1930). Dollfus (1932) described progenetic metacercariae from *Planorbis planorbis* and reported (p. 412), "Nous signalons le premier cas connu d'une métacercaire progénétique chez un mollusque d'eau douce. Le même planorbe héberge des sporocysts, les cercaires, les métacercaires enkystées et les métacercaires libres, vraisemblablement sorties de leur kyste." Since the larvae attained sexual maturity in their cysts and contained both spermatozoa and developing eggs, Dollfus admitted the possibility of self-fertilization.

Alice Buttner (1950a) stated (p. 21), "Les métacercaires progénétiques sont surtout fréquentes chez arthropodes (insectes, crustacés), ainsi que chez les poissons et les batraciens; elles ont été rencontrées également quelquefois chez des mol-

lusques." She reported for *Plagiorchis brumpti* the first experimental demonstration of an abbreviated life cycle in a digenetic trematode and predicated (p. 25), "La progénèse est, chez les trématodes, un phénomène tantôt constant, tantôt accidentel; dans ce dernier cas, les métacercaires non progénétiques restent susceptibles, comme les progénétiques, de devenir adultes chez un hôte définitif." In a comprehensive study of progenesis among digenetic trematodes, Mlle. Buttner (1950b, 1951) reviewed previous accounts, listed progenetic species in more than a score of genera and a dozen different families, and reported experiments showing constant, obligatory progenesis in *Paralepoderma brumpti* and *Ratzia joyeuxi* and inconstant, facultative progenesis in *Pleurogenes medians*. Other observations were made on identified and unidentified progenetic cercariae and metacercariae.

Biguet, Deblock and Capron (1956) described progenetic metacercariae from *Bithynia leachi* collected in the north of France. Dissection of these mollusks revealed an infection rate of more than 30 per cent, with one to twelve unencysted specimens in each host. The worms manifested varying degrees of maturity and about 10 per cent of the infected snails contained rediae with developing cercariae. Sporocysts were not observed. Comparison with the description of *A. progenetica* as given by Serkova and Bykhovskii (1940) and other described species disclosed differences which led the authors to designate their specimens as members of a new species, *Asymphylodora dollfusi*. Observations on the developmental cycles of *Asymphylodora tincae* and other digenetic trematodes were reported by Wisniewski (1956).

Observations on abbreviated life-cycles have been recorded also for members of other taxonomic groups. Progenetic metacercariae of hemiurid species were reported from copepods by Dollfus (1954) and by Chabaud and Biguet (1954). Adult specimens of another hemiurid were reported from *Sagitta elegans* by Betty Myers (1956). Crusz (1956) reported progenetic metacercariae of *Cercaria patialensis*, a species described by Soparkar (1924) from *Melanoides tuberculata* and related to *Transversotrema* by Witenberg (1944). Peters (1957) described *Allocreadium neotenicum* n. sp., from sexually mature specimens found in water beetles. Stunkard and Uzmann (1959) reported that sexually mature and gravid worms found in *Mytilus edulis* are specifically identical with *Cercaria milfordensis* Uzmann, 1953 and with *Proctoeces maculatus* (Looss, 1901). Freeman and Llewellyn (1958) described adult worms in the renal organs of the lamellibranch mollusk, *Scrobicularia plana*, taken from the flats of the Thames estuary, at Chalkwell in Essex and Whitstable in Kent. The specimens were identified as *Proctoeces subtenuis* (Linton, 1907), which Stunkard and Uzmann (1959) synonymized with *P. maculatus*.

The extent and incidence of progenetic maturity in larvae of digenetic trematodes have aroused questions in the minds of many investigators since Dollfus posed the problem. After reporting sexual maturity in metacercariae of a species of *Clinostomum*, McIntosh (1935, p. 79) wrote, "Do these records of precocious development throw light on what the adult flukes were like in the ages before the vertebrates came into being, or may the phenomenon be explained on the basis of the similarity of the environment of the metacercaria with that of the habitat of the adult?" Buttner (1951) attempted to evaluate the environmental factors which might affect sexual development and raised the question whether or not

progenesis might provide data concerning the origin of parasitism among the trematodes; whether it represents successive stages in the evolution of existing life-cycles or is merely an abridgment or simplification of otherwise more complicated cycles. She was inclined to regard progenesis as the result of a mutation in hereditary factors rather than as the result of environmental influences. Szidat (1956) discussed the causes and meaning of abbreviated life cycles in trematodes and cestodes. He stated that formation of eggs in the first intermediate host would undoubtedly be favorable for preservation of the species and that the addition of intermediate hosts might be explained as steps in the elaboration of a food-chain.

The origin of metagenesis, alternation of sexual and asexual generations, has received the attention of biologists for more than one hundred years. It was first recognized by Steenstrup in coelenterates and parasitic flatworms. Actually, the phenomenon was initiated and perfected in plants. In the early amphibious plants, liverworts and mosses, the sexual gametophyte was dominant and the asexual sporophyte arose as a microscopic and parasitic generation when germinal cells separated from the parent organism and, enclosed in a protective covering, proved capable of developing new gametophytes. It is probable that the development of the sporophytic generation was an adaptation to terrestrial existence. In the course of evolution, as represented by the pteridophytes, both generations were independent with the sporophyte gradually assuming the ascendancy, while in seed-bearing plants the asexual sporophyte became dominant with the sexual generation reduced to a few cells, entirely dependent and parasitic on the asexual one. In plants, the gametophyte is haploid and the sporophyte is diploid, with reduction of chromosomes at sporogenesis. In the Coccidia and other sporozoans, reduction is zygotic, whereas in the trematodes both generations are diploid and reduction is gametic. It appears, therefore, that the location in the life-cycle where the reduction divisions occur is not determinate in the evolution of metagenesis.

Among endoparasites, the parasite perishes with the host, and many species which became successful developed accessory, *i.e.*, asexual types of reproduction and provision for emergence and dispersal of the asexually produced individuals. The introduction of asexual methods was essentially similar in plants and animals. In both they evolved in a parasitic generation. In the protozoans which became cellular or histozoic parasites, sporulation became the characteristic method of reproduction with alternation of generations. Sporulation involves rapid nuclear divisions in a common cytoplasmic matrix, the formation of a plasmodium, and subsequent multiple fission with the production of many new individuals. In the asexual cycle, each cell which results from sporulation is termed a merozoite. Certain of these cells, usually after repeated divisions and the development of physiological maturity, become gametocytes and produce gametes. In the sexual cycle, the fusion of gametes produces a zygote which again undergoes sporulation and the production of sporozoites. Both types of reproduction may take place in the same host or, in other species, alternation of generations and hosts may occur.

The parasitic flatworms were derived from free-living species by gradual and progressive adaptation and present life-cycles are not primitive. The Digenea are distinct in morphology, bionomics and life-cycles from the Monogenea and

the origin of double hosts with alternation of generations, involving sexual and asexual types of reproduction, is still an unresolved problem. It is generally agreed that the Digenea have a common ancestry with the Turbellaria. In certain rhabdocoels, asexual reproduction regularly alternates with sexual reproduction. It appears that asexual reproduction is associated with rapid metabolism and a juvenile condition and that sexual maturity is attained with physiological maturity. The turbellarians are primitively carnivorous and certain dalyellioid species, probably related to the ancestors of the Digenea, are parasitic in mollusks and echinoderms. Others are commensals or pseudoparasites. Leuckart maintained repeatedly that the mollusk was the original host of the early digenetic trematodes and his argument was indorsed by Stunkard (1957).

It is accepted that endoparasitism frequently results in the acquisition of accessory, asexual methods of reproduction. If the ciliated larva of the turbellarian, on invasion of a mollusk, were to form a cyst-like structure in which the germinal cells were to separate and develop independently, a very efficient method of reproduction, polyembryony, would have arisen. The repeated dissociation of germinal cells could continue to form daughter sporocysts, but the progeny would tend eventually to develop turbellarian structures, notably a pharynx and simple gut, and a redia-like individual would result. Such a sexually mature stage may be discerned in members of the Aspidogastridae.

Polyembryony in sporocysts and rediae would produce population pressure and individuals would be expelled from the host. The finding of a new host required locomotion and the modification of the posterior portion of the body to form a device for sculling through the water gave a distinct advantage over mere wriggling movements or the successive attachments of suckers. The diversity in types of cercarial tails indicates the many directions in which this adaptation has progressed. The asexually produced individuals, on leaving their former hosts, would be dispersed throughout the neighboring area. Such worms, already pre-adapted for parasitic existence, would invade and become sexually mature in other animals, and in essential respects could be compared with present-day progenetic metacercariae. With the advent of vertebrates, these parasites together with their hosts were eaten; as a result the worms were introduced into new hosts. With establishment in the newly acquired vertebrate hosts, sexual maturity was naturally more and more deferred to worms in the definitive hosts. Meanwhile, the former definitive hosts became secondary intermediate, paratenic or transport hosts, providing for completion of the newly acquired life-cycle. The vertebrates, wider-ranging and longer-lived animals, would facilitate the dispersal and prolong the life of the parasites. After reviewing life cycles of parasitic worms in the different classes, Stunkard (1953) concluded, ". . . it is apparent that developmental cycles have been evolved concomitantly with the parasitic habit, that they are bionomic adaptations to ecological conditions, and that modifications in the course of the life-cycle were introduced accidentally and have been perpetuated because they facilitated dispersal and had survival value for the species." Progenesis occurs in members of many families; its distribution and incidence are too extensive to be explained as a mutation; rather it appears to be a relict, the persistence of an earlier state, which obtained before sexual maturity was so largely deferred to definitive vertebrate hosts.

LITERATURE CITED

ANNEREAUX, R. F., 1947. Three new trematodes from marine fishes of California. *Trans. Amer. Micros. Soc.*, **66**: 249–255.

VON BAER, K. E., 1826. Sur les entozoaires ou vers intestinaux. *Bull. Sci. Nat. et Géol., Paris,* **9**: 123–126.

VON BAER, K. E., 1827. Beiträge zur Kenntniss der niedern Thiere. *Nova Acta nat. curios., Bonne,* **13**: 523–762.

BELOUS, E. V., 1954. On the systematics of the trematode family Haploporidae Nicoll, 1914. (Russian text.) *Trudy Gel'mint. Lab. Akad. Nauk, SSSR,* **7**: 277–281.

BIGUET, J., S. DEBLOCK AND A. CAPRON, 1956. Description d'une métacercaire progénétique du genre *Asymphylodora* Looss 1899, découverte chez *Bythinia leachi* Sheppard dans le nord de la France. *Ann. Parasitol.,* **31**: 525–542.

BUTTNER, ALICE, 1950a. Première démonstration expérimentale d'un cycle abrégé chez les trématodes digénétiques. Cas du *Plagiorchis brumpti. Ann. Parasitol.,* **25**: 21–26.

BUTTNER, ALICE, 1950b. La progénèse chez les trématodes digénétiques (I, II). *Ann. Parasitol.,* **25**: 376–434.

BUTTNER, ALICE, 1951. La progénèse chez les trématodes digénétiques (III). *Ann. Parasitol.,* **26**: 19–66, 138–189, 279–322.

CHABAUD, A. G., AND J. BIGUET, 1954. Etude d'un trématode hémiuroide à métacercaire progénétique. I. Développement chez le mollusque. II. Infestation de copépode. III. Développement chez le copépode. *Ann. Parasitol.,* **29**: 527–545.

CRUSZ, H., 1956. The progenetic trematode *Cercaria patialensis* Soparkar in Ceylon. *J. Parasitol.,* **42**: 245.

DEBLOCK, S., A. CAPRON AND J. BIGUET, 1957. Contribution à la connaissance d'*Asymphylodora tincae* (Modeer, 1790). *Ann. Parasitol.,* **32**: 208–218.

DIESING, K. M., 1858. Berichtigungen und Zusätze zur Revision der Cercarieen. *Sitzungsb. Akad. Wissensch., Wien, Math-naturw. Cl.,* **15**: 377–400.

DOLLFUS, R. P., 1913. Contribution a l'étude des trématodes marins des côtes du Boulonnaise. Une méta-cercaire margaritigène parasite de *Donax vittatus* da Costa. *Mém. Soc. Zool. France,* **25**: 85–144.

DOLLFUS, R. P., 1924. Polyxénia et progénèse de la larve métacercaire de *Pleurogenes medians. C. R. Acad. Sci., Paris,* **179**: 305–308.

DOLLFUS, R. P., 1927. Sur une métacercaire progénétique d'hémiuride (Trém. Digen). *Bull. Biol. France, Belg.,* **61**: 49–58.

DOLLFUS, R. P., 1929. Existe-t-il des cycles évolutifs abrégés chez les trématodes digénétique? Le cas de *Ratzia parva* (Stossich, 1904). *Ann. Parasitol.,* **7**: 196–203.

DOLLFUS, R. P., 1932. Métacercaire progénétique chez un planorbe. *Ann. Parasitol.,* **10**: 407–413.

DOLLFUS, R. P., 1954. Métacercaire progénétique de *Derogenes* (Trematoda; Hemiuroidea) chez un copépode parasite de poisson. *Vie et Milieu,* **5**: 565–568.

DUBOIS, G., 1929. Les cercaires de la région de Neuchâtel. *Bull. Soc. Neuchât. Sci. Natur., 53 (n. sér.),* **2**: 1–177.

DE FILIPPI, F., 1837. Descrizione di nuovi entozoi trovati in alcuni molluschi d'acqua dolce. *Bibliot. Ital. Milano,* **87**: 333–340.

DE FILIPPI, F., 1854. Mémoire pour servir à l'histoire génétique des trématodes. *Ann. sci. nat. Paris, Zool., (ser. 4),* **2**: 255–284.

DE FILIPPI, F., 1855. Deuxième mémoire pour servir à l'histoire génétique des trématodes. *Mem. Accad. Sci. Torino, (sér. 2),* **16**: 419–442.

DE FILIPPI, F., 1857. Troisième mémoire pour servir à l'histoire génétique des trématodes. *Mem. Accad. Sci. Torino, (sér. 2),* **18**: 201–232.

FREEMAN, R. F. H., AND J. LLEWELLYN, 1958. An adult digenetic trematode from an invertebrate host: *Proctoeces subtenuis* (Linton) from the lamellibranch *Scrobicularia plana* (da Costa). *J. Mar. Biol. Assoc.,* **37**: 435–457.

FUHRMANN, O., 1916. Notes helminthologiques suisses. II. Une nouvelle espéce de cercaire sans queue. *Rev. Suisse Zool.,* **24**: 393–396.

FUHRMANN, O., 1928. Trematoda, in Handbuch der Zoologie; Kükenthal-Krumbach, 2 (lief. 3) Berlin.

GIARD, A., 1887. Sur la progenèse. *Bull. Sci. France, Belg.,* **18**: 25.

ISAICHIKOV, I. M., 1923. Study of parasitic worms from cyprinid fishes of the Kouban river. Travaux des Editions Encyclopédiques veterinaires de l'Etat, II, Livre 2: 1–12. (en russe). Cited after Biguet, Deblock et Capron (1956).

IVANITSKII, S. V., 1928. On the trematode fauna of Ukranian vertebrates. (Russian text). *Veter. Dilo, Kharkiv,* **2** (51): 30.

JOYEUX, CH., 1923. Recherches sur la faune helminthologique africaine. *Arch. Instit. Pasteur Tunis,* **13**: 328–338.

JOYEUX, CH., R. NOYER AND J. G. BAER, 1930. L'activité génitale des métacercaires progénétiques. *Bull. Soc. Path. Exot.,* **23**: 967–977.

KULAKOWSKAJA, O. P., 1947. *Asymphylodora markewitschi* n. sp., trématode digénétique des poissons du fleuve Dnieper. Trav. Instit. Zool. Acad. Sci. Repub. Ukranienne, No. 1: 152-154.

LOOSS, A., 1894. Distomen unserer Fische und Frösche. Bibl. Zool., Heft 16.

LOOSS, A., 1899. Weitere Beiträge zur Kenntnis der Trematoden-Fauna Aegyptens, zugleich Versuch einer natürlichen Gliederung des Genus *Distomum* Retzius. *Zool. Jahrb., System.,* **12**: 521–784.

LÜHE, M., 1909. Parasitische Plattwürmer. I. Trematodes. in Süsswasserfauna Deutschlands (Brauer). Heft 17.

MCINTOSH, A., 1935. A progenetic metacercaria of a *Clinostomum* in a West-Indian land snail. *Proc. Helminth. Soc. Washing.,* **2**: 79–80.

MARKEWITSCH, A. P., 1951. Faune parasitaire des poissons d'eau douce de la République d'Ukraine. Edit. Acad. Sci. Ukraine, pp. 1–376.

MARKOWSKI, S., 1935. Die parasitischen Würmer von *Gobius minutus* Pall. des polnischen Balticums. *Bull. Internatl. Acad. Cracovie, B,* **2**: 251–260.

MATHIAS, P., 1924. Contribution à l'étude du cycle évolutif d'un trématode de la famille des Pleurogenetinae Lss. (*Pleurogenes medians* Olss.). *Bull. Soc. Zool. France,* **49** 375–377.

MYERS, BETTY J., 1956. An adult *Hemiurus* sp. (Trematoda) from *Sagitta elegans* Verrill. *Canad. J. Zool.,* **34**: 206–207.

NAGANO, K., 1930. On the intermediate host of *Asymphylodora tincae* in Japan. *Trans. Parasit. Soc., Japan,* **2**: 24.

OZAKI, Y., 1925. On a new genus of fish trematodes, *Genarchopsus,* and a new species of *Asymphylodora. Jap. J. Zool.,* **1**: 101–108.

PETERS, L. E., 1957. An analysis of the trematode genus *Allocreadium* Looss with the description of *Allocreadium neotenicum* sp. nov. from water beetles. *J. Parasitol.,* **43**: 136–144.

RUDOLPHI, C. A., 1809. Entozoorum sive vermium intestinalium historia naturalis. **2** (1): 457 pp., Amstelaedami.

SERKOVA, O. P., AND B. E. BYKHOVSKII, 1940. *Asymphylodora progenetica* n. sp., nebst einigen Angaben über ihre Morphologie und Entwicklungsgeschichte. (Russian text, German summary) *Parazitol. Sborn Zool. Inst. Akad. Nauk SSSR. Leningrad,* **8**: 162–175.

SEWELL, R. B. SEYMOUR, 1922. Cercariae Indicae. *Indian J. Med. Research,* **10** (Suppl.): 373 pp.

VON SIEBOLD, CARL T. E., 1835. Helminthologische Beiträge. *Arch. Naturg.,* **1**: 45–83.

SINITSIN, D. F., 1905. Beiträge zur Naturgeschichte der Trematoden. Die Distomen der Fische und Frösche der Umgebung von Warschau. *Varsave, Izv. Univ.,* **1**: 1–210. (in Russian).

SKRJABIN, K. I., 1955. Trematodes of Animals and Man, **11**: 378–440. (in Russian).

SOPARKAR, M. B., 1924. A new cercaria from northern India, *Cercaria patialensis* nov. spec. *Indian J. Med. Research,* **11**: 933–942.

SRIVASTAVA, H. D., 1936. A rare parasite of the family Monorchidae Odhner, 1911, from an Indian freshwater fish (*Ophiocephalus punctatus*). *Ann. Mag. Nat. Hist., (10),* **17**: 319–324.

SRIVASTAVA, N. N., 1951. A new trematode, *Asymphylodora kederai* n. sp. of the family Monorchiidae Odhner, 1911. *Indian J. Helminth.,* **3**: 7–12.

STUNKARD, H. W., 1953. Life-histories and systematics of parasitic worms. *System. Zool.,* **2**: 7–18.

STUNKARD, H. W., 1955. The trematode genus *Asymphylodora*. Rev. Iberica Parasitol., Tomo Extraordinario, pp. 633–644.

STUNKARD, H. W., 1957. Host-specificity and parallel evolution of parasitic flatworms. *Zeitschr. Tropenmed. Parasitol.*, **8**: 254–263.

STUNKARD, H. W., AND J. R. UZMANN, 1959. The life-cycle of the digenetic trematode, *Proctoeces maculatus* (Looss, 1901) Odhner, 1911 [syn. *P. subtenuis* (Linton, 1907) Hanson, 1950], and description of *Cercaria adranocerca* n. sp. *Biol. Bull.*, **116**: 184–193.

SZIDAT, L., 1943. Die Fischtrematoden der Gattung *Asymphylodora* Looss, 1899, und Verwandte. *Zeitschr. Parasitenk.*, **13**: 25–61.

SZIDAT, L., 1956. Über den Entwicklungszyklus mit progenetischen Larvenstadien (Cercariaeen) von *Genarchella genarchella* Travassos, 1928 (Trematoda, Hemiuridae) und die Möglichkeit einer hormonalen Beeinflussung der Parasiten durch ihre Wirtstiere. *Zeitschr. Tropenmed. Parasitol.*, **7**: 132–153.

TAKEUTI, E., 1936. A new trematode, *Stèganoderma kamatsukae* from *Pseudogobio esocinus* (Temm. et Schleg.) *Zool. Mag.*, **48**: 581–583. (Japanese text, English abstract).

THOMAS, J. D., 1959. Trematodes of Ghanaian sublittoral fishes. I. The family Monorchiidae. *J. Parasitol.*, **45**: 95–113.

TSCHERNYSCHENKO, A., 1949. Nouveaux helminthes des poissons de la mer noire. Travaux Université d'Etat Metschnikoff d'Odessa, **28**: T. IV (57) in Skrjabin (1955) 12: 436–439.

WAGENER, G. R., 1857. Beiträge zur Entwicklungs-Geschichte der Eingeweidewürmer. Natuurk. Verhandel. Holland. Maatsch. Wetensch. Haarlem. 112 pp.

WALLACE, H. E., 1941. Life history and embryology of *Triganodistomum mutabile* (Cort) (Lissorchiidae, Trematoda). *Trans. Amer. Micros. Soc.*, **60**: 309–326.

WESENBERG-LUND, C., 1934. Contributions to the development of the Trematoda Digenea. Part II. The biology of the freshwater cercariae in Danish freshwaters. *K. Danske Vidensk. Selsk. Skr., Naturw. Math. Afd.*, **5**: 1–223.

WISNIEWSKI, W. L., 1956. Research on the parasites of Goldapiwo lake. Wiadom. *Parazytol.*, **2**: 213–215. (Polish text, English summary).

WITENBERG, G. G., 1944. *Transversotrema haasi*, a new fish trematode. *J. Parasitol.*, **30**: 179–180.

WITENBERG, G. G., AND F. ECKMANN, 1934. Notes on *Asymphylodora tincae*. *Ann. Mag. Nat. Hist.* (*10*), **14**: 366–371.

WUNDER, W., 1924. Bau, Entwicklung und Funktion des Cercarienschwanzes. *Zool. Jahrb., Anat.*, **46**: 303–342.

YAMAGUTI, S., 1936. Studies on the helminth fauna of Japan. Part. 15. Trematodes of fishes, II. Kyoto, pp. 1–6.

YAMAGUTI, S., 1938. Studies on the helminth fauna of Japan. Part 21. Trematodes of Fishes, IV. Maruzen Co., Tokyo, pp. 1–139.

YAMAGUTI, S., 1958. Systema Helminthum. Part 1. Digenetic Trematodes of Fishes. 371 pp., Interscience Publ., New York.

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Section 12 : Attraction of Fish.

SUMMARY OF EXPERIMENTS ON THE RESPONSE OF TUNA TO STIMULI

by

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Abstract

The aim of the experiments described in this paper was to obtain information which might lead to improved methods of tuna fishing, and especially in finding a substitute for baitfish. In a series of tank experiments, it was found that yellowfin and little tunny responded to white light of moderate intensity but not to a weak light. Their reactions to chemical stimuli were also observed and a positive response was obtained by using clear aqueous or alcohol extracts of tuna flesh. They were repelled, however, by copper acetate—the shark repellent. The possibility of electrofishing for surface tuna was investigated and since it was demonstrated that electrotaxis could be induced in tuna with an electric field of known characteristics, the problem becomes one of electrical engineering rather than of biology.

Résumé des expériences relatives à la réaction du thon aux stimuli

Résumé

Les expériences décrites dans cet article avaient pour but de recueillir des renseignements susceptibles de conduire à l'amélioration des méthodes de pêche au thon, et plus particulièrement de trouver le moyen de remplacer l'appât vivant. An cours d'une série d'essais en bassin, on a observé que les thons à nageoires jaunes et les "little tunny" (*Euthynnus yaito*) réagissaient à une lumière blanche d'intensité modérée mais non à une lumière faible. On a également observé leur comportement aux stimuli chimiques et l'on a obtenu une réaction positive par l'emploi d'extraits aqueux ou alcooliques de chair de thon. Toutefois, l'acétate de cuivre, utilisé pour écarter les requins, les a éloignés. La possibilité de pêcher les thons de surface à l'électricité a été étudiée. et comme il a été démontré que l'on pouvait provoquer l'électrotaxie chez le thon au moyen d'un champ électrique de caractéristiques connues, le problème relève plus de la technique de l'électricité que de la biologie.

Resumen de los experimentos sobre la reacción del atún a los estímulos

Extracto

Los experimentos descritos en este trabajo tuvieron por objeto reunir información para encontrar métodos mejorados de pesca de atún y, especialmente, un sustitutivó del cebo vivo. En una serie de experimentos en estanques se encontró que el atún de aleta amarilla y el atunito reaccionaban bien a la luz blanca de intensidad moderada pero no así a una débil. Además se observó el efecto de las substancias químicas lográndose una reacción al usar extractos acuosos o alcohólicos transparentes de carne de atún. Sin embargo los peces se alejaron al utilizar acetato de cobre que se utiliza para repeler a los tiburones. También se investigó la posibilidad de emplear la electricidad para la captura de los peces que nadan en la superficie, demostrándose que es posible producir la electrotaxia en el atún mediante un campo eléctrico de características conocidas, pero este problema cae más bien dentro del terreno de la ingeniería eléctrica que de la biología.

DURING the period 1951 and 1956, several staff members of the University of Hawaii conducted experiments, under contract with the Pacific Oceanic Fishery Investigations (POFI) of the U.S. Fish and Wildlife Service, on the response of tuna to various types of stimuli. The writer was leader of several of these projects prior to joining the Service in 1955. This is a brief summary of the work to date.

The primary objective of the study was to obtain information which might suggest new or improved methods of tuna fishing. Efforts were directed particularly at devising a substitute for baitfish, the scarcity and high mortality of which limits the catch of surface tuna in Hawaii and prevents the expansion of the live-bait fishery to potentially productive offshore areas.

ESTABLISHING TUNA IN CAPTIVITY

Methods of fishing, transporting and establishing tuna in captivity are described by Tester[6]. Several species of tuna and tuna-like fish were caught by surface trolling off the windward shore of Oahu, including the skipjack (*Katsuwonus pelamis*), yellowfin (*Neothunnus macropterus*), and little tunny (*Euthynnus yaito*). Immediately after capture, fish were placed in the vessel's livewell (67½ × 43 × 32 in.), which was supplied with running sea water (20 to 40 gallons/min.) but which, in addition, was aerated with finely-divided bubbles of oxygen from a pressure tank. They were then transported to ponds and tanks at the Hawaii Marine Laboratory (1 to 2 hours run), to which they were transferred by dipnet. Yellowfin (about 2 to 8 lb. in weight) and little tunny (about 1 to 6 lb. in weight) were successfully established in one of the large ponds (350 ft. long, 65 ft. wide and averaging about 6 ft. deep) which was flushed by tidal currents. Yellowfin and little tunny were also maintained in a concrete tank (35 ft. long, 11 ft. wide and 4 ft. deep) which was supplied with running salt water (about 25 gallons/min.). Skipjack were not successfully established;

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of numerous trials only one fish was transported alive from the fishing grounds to the laboratory and it died shortly after being released into the tank.

Except when on an experimental diet, the little tunny and yellowfin were fed cut-up fish, usually small tuna which died during our fishing operations or large tuna from POFI longline catches. The tunas generally started to feed within a week of introduction; otherwise they would die. When feeding fish were already present in the pond or tank, newly introduced fish would usually join the school and start to feed within one or two days.

The established (feeding) tuna survived for various lengths of time, ranging from but a few days to over 2 years. Some loss occurred from extraneous factors such as poaching or accidental stranding of the fish on dry land. Several of the fish developed partial or complete blindness and died either from starvation or injury. Others eventually became "sick", they moved slowly, listlessly and individually, ceasing to feed and eventually dying. Mortality occurred mostly during the fall and winter, and perhaps was associated with lowered temperature and salinity in the inshore environment.

Yellowfin, both in the live well of the boat and in the pond and tank, were relatively slow, leisurely swimmers. When two fish were present, they usually swam together. When several were present, they formed a loose school but often swam individually or in two's or three's. In contrast, the little tunny were rapid swimmers and usually formed a single, compact school. On occasions, when a large population (15 to 30 fish) was present in the pond, they formed two schools, but rarely more.

More detailed observations on the captive fish are included in the papers summarized below.

RESPONSE TO VISUAL STIMULI

During the summer of 1951, Hsiao[1] studied the response of two yellowfin and five little tunny to artificial light. The fish were confined in the concrete tank. The experiments were performed after dark, with the tank illuminated constantly with two 60 W. bulbs. He found that both yellowfin and little tunny were attracted to continuous white light over a range of moderate intensity (about 70 to 450 ft. candles). They were not attracted by a light of weaker intensity, and they were repelled by a light of stronger intensity. Both species were attracted to coloured lights of moderate intensity, but to no greater extent than to white light. Similar results were obtained with interrupted white light. There appeared to be no relationship between the strength of the response and the frequency of interruption of the light. Although the tuna approached an interrupted light of moderate intensity, they were repelled from the near vicinity at the instant the light flashed either on or off.

The above experiments suggest that tuna at sea might respond to continuous light of moderate intensity. To my knowledge, however, only tuna larvae and young have been caught by this method. If adults in their natural habitat were attracted by light, it seems likely that this already would have been discovered and utilized by tuna fishermen.

The response of a school of 12 captive little tunny to moving objects of various colours in the large pond was studied by Hsiao and Tester[2] during the summer of 1952. During daylight hours, a pair of lures was momentarily dipped into an "attraction" area once every 2 sec. by a remote control from a high tower. The lures consisted of 2 in. sections of rubber tubing of various colours. The number of "fish-seconds" in the area, the number of "passes" at the lures, and the time were recorded on a kymograph. Observations were made under control conditions, when lures were introduced, and when lures were used along with an extract of tuna flesh (see later) which was introduced into the pond from one end. Activity of the fish (number of school entrances, time spent in the area, and swimming speed) was greater when lures were used, as compared with control conditions, and was still greater when lures and extract were used together. Although, in general, the fish made more passes at white than at coloured lures (red, black, silver), the superiority of the white lures was slight. It may have been associated with greater visibility rather than colour preference. There is no assurance that white lures would be superior to coloured lures in the open ocean. Trolling data collected during 1951 and 1953 (Tester and Nakamura[9]) show no preference by the tuna with respect to either form or colour of the lure.

The above experiments deal with only one aspect of visual response, namely lure preference. Specific pond experiments on visual acuity were not undertaken. Casual observations indicated, however, that both yellowfin and little tunny could perceive objects such as stones or pieces of food which were thrown to them while the objects were still in the air. The fish would speed rapidly toward the point where such objects would hit the water. If the objects were not thrown so that the fish could see them in transit, the tuna could be attracted either by the splash made when the object hit the water, or perhaps by the object itself over a distance of about 50 ft.

In view of the conclusion (see later) that visual perception was of prime importance in attracting tuna to the stern of a fishing boat by the use of livebait, Matthews[3,a] studied the comparative morphology of tuna eyes, during 1955-56, using species of diverse habits and habitats (skipjack, yellowfin, and bigeye). No significant differences were observed. In addition, he conducted experiments to determine the focal length of the lens and other optical properties of the excised eyes of freshly-killed tuna immersed in a long salt trough, viewing a light source through a "window" in the chorion of the vitreous chamber, but with confusing results (unpublished). Contract work in 1956-57 was devoted to a study of the comparative histology of the retina in skipjack, yellowfin, bigeye, and albacore, including observations on the frequency and arrangement of the rod-cone mosaics. Preliminary results[3,b] indicate a relatively large number of rods in the retina of the albacore, suggesting relatively greater adaptation to dim light than with the other three species.

RESPONSE TO AUDITORY STIMULI

Miyake[4] conducted experiments with captive yellowfin and little tunny during 1951-52 to discover (1) if tuna

produced any sound and (2) if they could be attracted or repelled by sounds of various frequencies. Using a listening frequency ranging from about 0·1 to 70 kc., he was able to identify low frequency sounds produced by the sudden movement of the tail of the yellowfin in the tank. This might have some significance with respect to the mechanism of school formation. No sounds produced by tuna were detected at listening frequencies in the moderate, high, or supersonic range. In attempting to attract or repel tuna by continuous sound stimulation in the pond, sounds were emitted at many frequencies from 0·1 to 70 kc. Although the results were inconclusive, there were indications that yellowfin might be attracted by complex sounds of low frequency.

RESPONSE TO CHEMICAL STIMULI

Van Weel[12] studied chemoreception in both yellowfin and little tunny in the concrete tank during 1951. He found that both fish had a well-developed sense of smell or taste whereby they were attracted to certain food substances. They were strongly attracted to clear, colourless extracts of tuna flesh. Moreover, it was found that the attractant was contained in the *protein* rather than in the *fat* fraction of the clear extract. In general, the response of the little tunny was more pronounced than that of the yellowfin. On the other hand, there was no positive response of either species to *conditioned* water in which baitfish had been living, nor to extracts of either baitfish or squid. Copper acetate, a shark repellent, was also repellent to tuna, although its effect was not as pronounced as on fish of other species which were also present in the tank.

The above study was continued in 1952-53 by Tester, Van Weel, and Naughton[10]. In the tank, improvements were made in the techniques of observation, introduction of test material, and measurement of the response. Testing was hampered by accumulation of test materials because of the small volume of water in the tank and its slow replacement. This problem was reduced by conducting tests on tuna established in the large pond, introducing test material through a continuous stream of water supplied at one end of the pond by a pump, and observing the response of the fish from a 20 ft. tower, which overlooked an "attraction" area extending from about 40 to about 80 ft. below the outlet. Pond testing was hampered by such factors as poor visibility due to weather, power failure, and erratic behaviour of the fish.

The results confirmed Van Weel's[12] observations that a positive response was obtained from clear, aqueous or alcohol extracts of tuna flesh. This took the form of a feeding reaction and included one or more of the following components: speeding or acceleration of the swimming rate, a return to the area of stimulation, surfacing, fanning-out and eventually a breakdown of school formation, circling, splashing, and biting at incidental objects on the surface of the water. It was postulated that an attractant was present in the flesh, viscera and blood of several species of tuna and certain other fish. Successful methods of concentration and preservation of this substance were achieved in preparation for large-scale sea-testing. Considerable time was devoted to its fractionation, purification, and identification.

In addition some 40 chemical compounds were tested, including amino acids, vitamins, aromatics, proteins, etc. With some of these there seemed to be a sensing of the dissolved or suspended materials but in no case did the response include all the typical components of a feeding reaction induced by fish extract.

The conditioning of the tuna was discussed with respect to their response to fish extract. Obviously they had become conditioned to feeding on inert, dead rather than motile, living food for they had little interest in schools of small baitfish which at times were present in the pond in fair abundance and which would leisurely withdraw as the tuna approached. Obviously, also, they had become conditioned to being fed for they would mill close to an observer on his approach to the pond. It was concluded that the response of the tuna was not directly conditioned by the kind of food, i.e. the species of fish used as food. However, there was the possibility that the tuna formed an association between feeding and the smell or taste of the dead food, which was cut up or otherwise macerated and which might exude juices of similar composition. If so, the response would not necessarily be obtained from wild fish at sea.

Tester, Yuen and Takata[11] reported on further experiments with little tunny in the pond and with skipjack schools at sea. Pond experiments were improved by introducing test substances into a continuous stream of water which flowed directly into the attraction area at the foot of the observation tower. Continued screening of some 75 known compounds indicated a mere "sensing" of strong smelling materials. A carefully designed experiment involving feeding the fish at successive weekly intervals with cut-up squid, skipjack, and shrimp and testing their response to extracts of these same substances was conducted. A response to all three extracts was obtained regardless of the food being fed, but the response to a particular extract was slightly greater when the substance from which it was prepared was being used as food. This experiment tended to confirm the suspicion voiced earlier that the fish were conditioned to the smell of juices exuded from the food which presumably contained common or similar substances which stimulated the feeding response. It was hoped that, even so, tuna in their natural environment would respond to the extract, which might contain a substance exuded by living, injured, or uninjured prey to which "wild" fish were naturally conditioned. This hope was not realized.

Large quantities of extracts of skipjack, yellowfin, and anchovy were prepared during the winter, spring, and summer of 1953, tested on the captive little tunny and presented to schools of skipjack at sea. In a few instances the schools consisted mostly of skipjack but included yellowfin, little tunny, or frigate mackerel. In some tests the concentrated liquid extract was sprayed on the surface or pumped in a stream in the path of the schools. In others, it was presented to schools which had been *chummed** to the stern of the vessel by livebait (*Stolephorus purpureus*). The results were either negative or inconclusive. Unchummed schools could not be stopped by an arc or circle of extract. Chummed schools could not be held at the stern even when the extract was

**Chum*—live or chopped fish used as a lure.

bucketed overboard. In a few tests, on releasing a large quantity of the extract after the school had been chummed to the stern and chumming was stopped, a few fish were seen jumping in or passing through the material. It was uncertain whether they were responding to the extract or chasing stray baitfish. The apparently negative results discouraged any further testing of extracts except in conjunction with lures as reported below.

RESPONSE TO EDIBLE AND INEDIBLE LURES

Tester, Yuen, and Takata[11] describe pond tests with edible lures, and sea trials with both edible and inedible lures. The pond tests showed that little tunny would eat edible preparations such as gelatin capsules, pieces of macaroni, and strips of agar gelatin, and that these were more avidly consumed it they were made chemically attractive, or palatable, with concentrated extracts of skipjack or anchovy. In some cases, also, the feeding response seemed to be greater if the lures were made more visually attractive, i.e., silvery in colour. The fish showed a distinct preference for the agar preparations.

Again, the results of sea tests of edible lures were negative. However, they were conducted during the autumn when skipjack schools were scarce and erratic in their behaviour. Several of the schools which failed to respond to our most promising preparation (agar strips impregnated with concentrated extract and with aluminum powder) also failed to respond to livebait.

Several types of inedible lures were tested at sea. These were used as chum both alone and along with liquid extract after the fish had been initially chummed to the stern of the ship with baitfish. There was a momentary response to shiny objects such as strips of tin (several of which were eaten), to silvery objects such as squares of aluminum foil, and to effervescing objects such as calcium carbide pellets. Similarly there was a momentary response to dead baitfish. The addition of extract had no apparent effect. The results indicated that the sense of vision plays a much greater role in feeding than the sense of smell. However, neither the visual lures nor a "drag-lure array" (designed to simulate a school of baitfish) towed behind the vessel, was successful in holding the fish at the stern.

On the hypothesis that motion was an essential component in visual attraction, attempts were made (unpublished) to devise an expendable, self-propelled motile lure which would simulate baitfish movement, and which would be made both visually and chemically attractive. Many types of "motors" (mostly generating air or gas) were devised, but none was satisfactory. A compressed-air "machine gun" was designed to project and at the same time activate compressed air cartridges. Following an unsuccessful sea trial, hampered by imperfections in the machine and poor behaviour of the released cartridges, this idea was abandoned.

RESPONSE TO ELECTRICAL STIMULI

Before conducting experiments on the response of tuna to electrical stimuli, it was considered best to obtain pertinent basic data on a more readily available marine species which could be easily kept in captivity. During 1951, Tester[7] studied the response of aholehole (*Kuhlia sandvicensis*) to interrupted direct current using a D.C. generator and various types of mechanical interrupters In a small salt water tank ($12 \times 2 \times 1$ ft.) the fish were forced to swim to the positive electrode when subjected to suitable combinations of current and frequency of interruption. The results indicated that, at a frequency of 15 cycles a progressive saving of power could be obtained by reducing the "current-on" fraction of a cycle from about 0·7 to 0·1. Power conservation, of course, is an important consideration in the practicality of marine electrofishing.

The above results were confirmed and extended by Miyake and Steiger[5] in further experiments with aholehole during 1954 and 1955, using storage batteries as the source of power. They concluded that the optimum frequency for electrotaxis was 10 cycles and that the minimum peak current for satisfactory response (12 amp) was associated with an "on-fraction" of 0·06 to 0·08. Total peak current requirements decreased with increase in length of the fish extrapolating the above results, they concluded that a current of 130 amp. at a potential of 60 V. would be required to induce electrotaxis in a fish the size of a small tuna (30 cm.) using plane 11×4 ft. electrodes spaced a distance of 33 ft. This was best achieved by condenser discharge. Accordingly an apparatus was constructed for experiments with tuna and other large fish in the concrete tank. It consisted of a bank of capacitors (55,000 mfd.) charged by any number up to 10 pairs of automobile storage batteries arranged in series parallel. The charging and discharging of the capacitors was controlled by a variable speed mechanical contactor.

With electrodes spaced at 33 ft. perfect electrotaxic response was obtained with a jack (*Carynx sp.*), using 60 V. (2 banks of 10 batteries) at 10 cycles. However, with little tunny and yellowfin the results were either inconclusive or negative. By spacing the electrodes a distance of 16 ft., thus increasing the electric field, an excellent electrotaxic response was repeatedly obtained with yellowfin tuna (about 50 cm. in length). The results showed that power requirements decreased (10 to 6 pairs of batteries) as the frequency increased to 20 cycles, the limit of the apparatus. Theoretical calculations indicated that 23 times as much power would be dissipated in the open sea as in the closed tank and that a correspondingly higher power output would be required to effect electrotaxis with the same electrode spacing and frequencies

In the same report, Miyake and Steiger[5] presented theoretical studies of the potential, electric field, and current density for spherical electrodes submerged in a large body of water. They also investigated the theoretical relation ship between the head-to-tail potential and current density in a fish as determined by the relative conductivities of the fish and water.

Following the 1954-55 results, reported above, the possibilities of utilizing an amplidyne to generate a pulsed direct current of satisfactory strength, waveform, and frequency for inducing electrotaxis were investigated in the laboratory with promising results (unpublished). Unfortunately continuation of the contract work has not been possible because the contractors have assumed other responsibilities.

DISCUSSION

Despite the large amount of information which has been obtained on the response of both captive and wild tuna to stimuli of various kinds, little progress has been made toward attaining the main objective. This was to devise a method of catching surface tuna, which was independent of the use of livebait.

It was realised at the outset that our approach was largely "trial and error" and that the probability of success was small. It was also realized that results obtained on captive fish, conditioned to pond life, might not be capable of extrapolation to wild fish of the open sea. Nevertheless, the approach seemed worthwhile in providing leads which might be tested by sea trials.

The pond tests demonstrated that the active little tunny and the less active yellowfin both have a keen sense of smell (or taste), together with excellent vision both through water and, with a calm surface, through air. The sea tests indicated that the sense of smell plays little, if any, part in natural feeding, although this is still an open question (a) because of the difficulty in making observations on the response of fish at sea, and (b) because the materials tested may not have included those which might be associated with living prey. These studies might well be repeated or perhaps extended in view of our recent discovery of a natural laboratory, a spot or "concourse" in the lee of an island where skipjack are always present and where their behaviour and response may be readily observed by underwater viewing devices which are presently being perfected.

Sea tests further indicated that vision played an important, and perhaps a dominating part in natural feeding and that motility of a lure, whether living or dead, whether edible or inedible, was an important attribute. These observations, also, can be repeated and extended at the skipjack concourse.

Although most of our pond observations were made on little tunny and, to a lesser extent, on yellowfin, our sea tests were conducted mostly on schools of skipjack. This again leaves an element of uncertainty in drawing conclusions regarding the negative results of sea tests.

The response of tuna to auditory stimuli was not adequately investigated; this work was abandoned in favour of the more promising fields of chemical and electrical stimulation.

The possibility of electrofishing for surface tuna, either with or without the use of bait, remains a promising area of study. Now that it has been demonstrated that electrotaxis may be induced in tuna with an electric field of known characteristics, the problem is one of engineering rather than biology.

Future efforts to devise new or improved methods of tuna fishing will be enhanced by further studies of the behaviour of tuna and their response to factors of the environment. Behaviour studies are rapidly becoming one of the major areas of research of the Pacific Oceanic Fishery Investigations and will occupy more and more of our attention in the years to come.

REFERENCES

[1] Hsiao, Sidney C. Reaction of tuna to stimuli—1951. Part III. Observations on the reaction of tuna to artificial light. U.S. Fish and Wildlife Service, Spec. Sci. Rept.—Fish. No. 91, pp. 36-58. 1952.

[2] Hsiao, Sidney C. and Tester, Albert L. Reaction of tuna to stimuli—1952-53. Part 2. Response of tuna to visual-chemical stimuli. U.S. Fish and Wildlife Service, Spec. Sci. Rept.—Fish. No. 130, pp. 63-76. 1955.

[3] Matthews, Donald C. MS. (a) A comparative morphological study of tuna eyes. MS. (b) A comparative histological study of tuna retinae.

[4] Miyake, Iwao. Reaction of tuna to stimuli—1951. Part IV. Observations on sound production and response in tuna. U.S. Fish and Wildlife Service, Spec. Sci. Rept.—Fish. No. 91, pp. 59-68. 1952.

[5] Miyake, Iwao and Steiger, Walter R. The response of tuna and other fish to electrical stimuli. U.S. Fish and Wildlife Service, Spec. Sci. Rept.—Fish. No. 223 (in print). 1957.

[6] Tester, Albert L. Establishing tuna and other pelagic fishes in ponds and tanks, U.S. Fish and Wildlife Service, Spec. Sci. Rept.—Fish. No. 71, 33 p. 1952a.

[7] Tester, Albert L. Reaction of tuna to stimuli—1951. Part I. Background and summary of results. U.S. Fish and Wildlife Service, Spec. Sci. Rept.—Fish. No. 91, pp. 1-7. 1952b.

[8] Tester, Albert L. Reaction of tuna to stimuli—1951. Part V. Notes on the response of a tropical fish (*Kuhlia sandvicensis*) to interrupted direct current. U.S. Fish and Wildlife Service, Spec. Sci. Rept.—Fish. No. 91, pp. 69-83. 1952c.

[9] Tester, Albert L. and Nakamura, Eugene L. Catch rate, size, sex, and food of tunas and other pelagic fish taken by trolling off Oahu, Hawaii, 1951-1955. U.S. Fish and Wildlife Service, Sp. Sci. Rept.—Fish. No. 250, 1957.

[10] Tester, Albert L., Van Weel, P. B. and Naughton, John J. Reaction of tuna to stimuli—1952-53. Part I. Response of tuna to chemical stimuli. U.S. Fish and Wildlife Service, Spec. Sci. Rept.—Fish. No. 130, pp. 1-62. 1955.

[11] Tester, Albert L., Yuen, Heeny and Takata, Michio. Reaction of tuna to stimuli, 1953, U.S. Fish and Wildlife Service, Spec. Sci. Rept.—Fish. No. 134, pp. 33. 1954.

[12] Weel, Van P. B. Reaction of tuna to stimuli—1951. Part II. Observations on the chemoreeption of tuna. U.S. Fish and Wildlife Service, Spec. Sci. Rept.—Fish. No. 91, pp. 8-35. 1952.

" Modern Fishing Gear of the World," published April, 1959, by Fishing News (Books) Ltd., 110 Fleet Street, London, E.C.4, and printed by Merritt & Hatcher Ltd., High Wycombe and London.

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A STUDY OF LOCALIZED PREDATION ON MARKED CHINOOK SALMON FINGERLINGS RELEASED AT McNARY DAM

RICHARD B. THOMPSON

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A STUDY OF LOCALIZED PREDATION ON MARKED CHINOOK SALMON FINGERLINGS RELEASED AT McNARY DAM

Richard B. Thompson①

During 1955 and 1956 the Department of Fisheries of the State of Washington conducted studies relating to mortality of downstream migrant salmon passing McNary dam.② Basically, this consisted of releasing test and control lots of marked chinook salmon (*Oncorhynchus tshawytscha*) fingerlings over the spillway and through the turbines at McNary dam on the Columbia River near Umatilla, Oregon, and recovering the fish at various points downstream. Observations on the 1955 releases indicated possible losses of the test fish to scrapfish predators immediately below the dam. Such losses could effect the validity of the test results. The dam mortality studies were repeated in 1956. During the entire marked-fingerling release period, from March 9 to 28, collections of resident and migratory game and scrap fishes were made in the area within 3 miles downstream of the dam. The objective of the collections and stomach examinations was to determine the degree of predation immediately below the dam and whether or not such predation, if found to occur, was sufficiently selective on either the experimental or control lots to bias the test results.

Graduated mesh gill nets (1¼" to 4", stretched measure) and trot lines were used to collect a total of 1,965 fishes of sixteen species (Table 1). Shiners, whitefishes, and suckers, all non-predatory species, made up the bulk of the catch, comprising 75 percent of the total number of fishes captured. The stomachs of the fishes were examined for evidence of the marked salmon fingerling remains. Such remains, though possibly the result of scavenging, were accepted as evidence of predation.

Initially, the stomachs of all fishes captured were examined. It was thus established which species were non-fish eaters and presumably non-predaceous on young salmon. The stomachs of the three species classed as predators, squawfish (*Ptychocheilus oregonensis*), brown trout (*Salmo trutta*), the sculpins (*Cottus spp.*) were thoroughly examined. The steelhead trout (*Salmo gairdneri*) were found to be non-feeding, upstream-migrating adults as a result of the examination of seven found dead in the net. The other eleven steelhead were alive when removed from the net and were released.

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① Fishery Research Biologist, Fish and Wildlife Service.

② Schoeneman, Dale, Charles O. Junge, Jr., Wallace E. Bostick, and Thomas K. Meekin. Research relating to the mortality of down-stream migrant salmon passing McNary dam. State of Washington, Department of Fisheries. Final Report: Army Engineers Contract No. DA-35026-Eng-20893. Mimeo. 1955.

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TABLE 2—Results of the examination of the predatory fishes collected below McNary Dam, March, 1956.

Species	Number Examined	Number Empty	Stomach Contents
Squawfish	106	91	Three contained one salmon fry each. Other foods were: other fishes, crayfish, and miscellaneous items, all in minute quantities.
Sculpin	18	18	
Brown trout	2	1	The one with food contained five salmon fry, presumed to be marked.
Steelhead	7	7	

From the examination of the stomachs of the three predatory species, it was evident that these fishes were eating little food during the collecting period (Table 2). Eighty-six percent of the squawfish had empty stomachs; the others contained only small quantities of non-salmonoid fishes, crayfish, salmon, and miscellaneous items. All the stomachs of the sculpins and steelheads examined were empty, and one of the two brown trout stomachs was empty.

Eight salmon fingerlings were found in the fishes examined. None of these was definitely identified as a tattooed fish released in the mortality experiments. It is assumed, however, that they were, for few unmarked (wild) salmon were captured in the Washington Department of Fisheries' recovery nets. Since 660,000 marked chinook salmon fingerlings were released in the 1956 dam mortality experiments, the rate of predation indicated by the recovery of eight fish is quite low.

During the period of salmon releases (March 9 to 28) the waters of the Columbia River at McNary dam were cold and turbid. Water temperatures varied between 39 and 40 degrees Fahrenheit. Secchi-disc readings ranged from 0.3 to 2.2 feet and averaged 1.15 feet on release days. It is felt that such conditions of low visibility and low water temperatures minimized the effectiveness of the predators in finding and feeding on the released salmon fingerlings.

The results of this study indicated that predation was too slight to bias the dam mortality test results.

TABLE 1—Total catches of fishes below McNary dam, March, 1956.

Species	Number Captured
Squawfish, *Ptychocheilus oregonensis*	106
Chub, *Mylocheilus caurinus*	31
Chiselmouth, *Acrocheilus alutaceus*	277
Shiner, *Richardsonius balteatus*	615
Hybrid, Squawfish X Chiselmouth	3
Coarse-scaled sucker, *Catostomus macrocheilus*	151
Fine-scaled sucker, *Catostomus syncheilus*	251
Mountain sucker, *Pantosteus jordani*	4
Whitefish, *Prosopium spp.*	448
Sculpin, *Cottus spp.*	18
Sturgeon, *Acipenser transmontanus*	24
Black crappie, *Pomoxis nigromaculatus*	8
Trout-perch, *Columbia transmontana*	1
Carp, *Cyprinus carpio*	8
Brown trout, *Salmo trutta*	2
Steelhead, *Salmo gairdneri*	18
	1,965

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FECUNDITY OF THE ARCTIC CHAR, *SALVELINUS ALPINUS*, OF THE WOOD RIVER LAKES, BRISTOL BAY, ALASKA.—In the Wood River Lakes region of Alaska, the Arctic char, *Salvelinus alpinus* (Linnaeus), is one of the principal predators on the juvenile sockeye salmon (*Oncorhynchus nerka*). The fishery for the adult sockeye is of great economic importance to the area. The following fecundity study was designed as a basic part of the life history study of the char and the determination of the char's role in the survival of the sockeye during their freshwater residence.

The sample of ripening female char was obtained from gill-net catches from Lake Nerka of the Wood River Lakes chain in 1954. Mesh sizes of the nets ranged from one and one-half to four inches, stretched measure. Lengths, weights, stomach contents, and degree of maturity of the fish were obtained and recorded. Ovaries were removed and preserved in 10 percent formalin solution, care being exercised to preserve the identification of each ovary with respect to right or left and with the fish from which both ovaries came.

The lengths referred to are fork lengths, the distance from the tip of the snout to the fork of the tail.

The seventy-one female char examined in this study ranged in length from 375 to 545 millimeters (15.2 to 22.2 inches) and in weight from 600 to 1,850 grams (1 pound, 5 ounces to 4 pounds, 1 ounce).

To enumerate the preserved and hardened ova, the mesovarium was first removed so that each ovum was free. Two 100-ova samples from each ovary were counted, and the volume of each determined by volumetric displacement in a 25-milliliter graduated cylinder. The remainder of the ova was then placed in a 250-milliliter graduated cylinder, and the volume of the sample determined by water displacement. The total calculated number of ova in each ovary was obtained by use of a simple ratio formula.

To verify the accuracy of the method, the ova in sixteen ovaries were counted individually after the calculated number had been obtained by the sample-displacement method. The absolute mean error was determined to be 1.09 percent.

The results of the fecundity estimates are shown in Table 1. The relative fecundity values given in the table are expressed both in weight and length. Length-relative fecundity is the num-

TABLE 1

CHARACTERISTICS AND FECUNDITY ESTIMATES OF 71 ARCTIC CHAR, *SALVELINUS ALPINUS*, FROM WOOD RIVER LAKES, ALASKA

Item	Mean	Range	Standard deviation
Fork length (millimeters)	438.5	375–545	35.9
Weight (grams)	986.5	600–1,850	288.9
Number of ova			
Left ovary	992.6	601–2,075	342.3
Right ovary	933.4	495–2,072	299.2
Total	1,926.0	1,182–4,038	191.7
Relative Fecundity			
Ova per centimeter of fork length	43.4	28.67–79.18	10.84
Ova per 100 grams of body weight	197.3	129.1–271.3	31.99

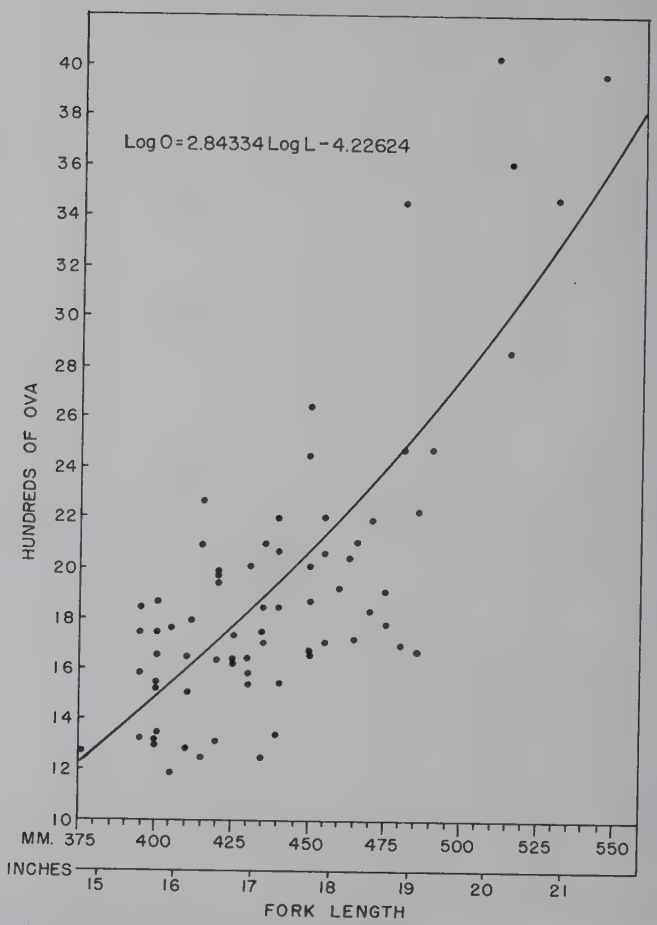


Fig. 1.—Length-fecundity relationship of a sample of seventy-one Arctic char, *Salvelinus alpinus* from Lake Nerka, Bristol Bay, Alaska.

ber of ova per centimeter of fork length; weight-relative fecundity, the number of ova per one-hundred grams of body weight.

The length-fecundity relationship of the Arctic char is shown in Figure 1. An acceptable regression line, determined by the least-squares method, was found to be expressed by the equation:

$$\mathbf{Log\ O} = 2.84334\ \mathbf{Log\ L} - 4.22624$$

where **O** is the total number of ova and **L** is the fork length in millimeters.

The mean egg content of the left ovary exceeded that of the right (Table 1) in 68 percent of the ovaries. When a greater number was present in the right ovary, the difference between the two was small.

From a small sample of almost ripe females it was found that the average percentage of body weight represented by the ovaries was 24.2 ± 4.6 percent.

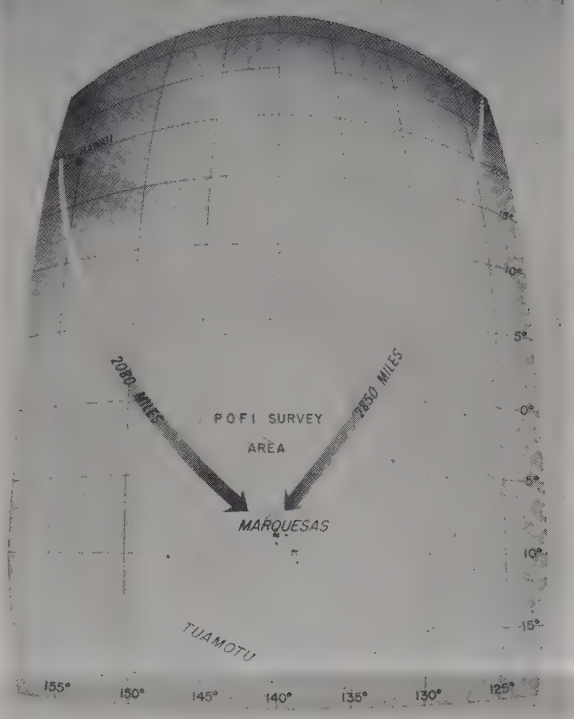
From this study it was determined that for comparative purposes, fecundity can best be shown by two statistics, (1) a length-fecundity regression line and (2) the relative fecundity based on number of ova per unit of fish length.—Richard B. Thompson, *Bureau of Commercial Fisheries Biological Laboratory, Seattle 2, Washington.*

Tuna Season in the Marquesas

By
ROBERT C. WILSON
and
THOMAS S. AUSTIN

". . . The Marquesas! What strange visions of outlandish things does the very name spirit up! . . . As we draw near the land, I hailed with delight the appearance of innumerable sea fowl."

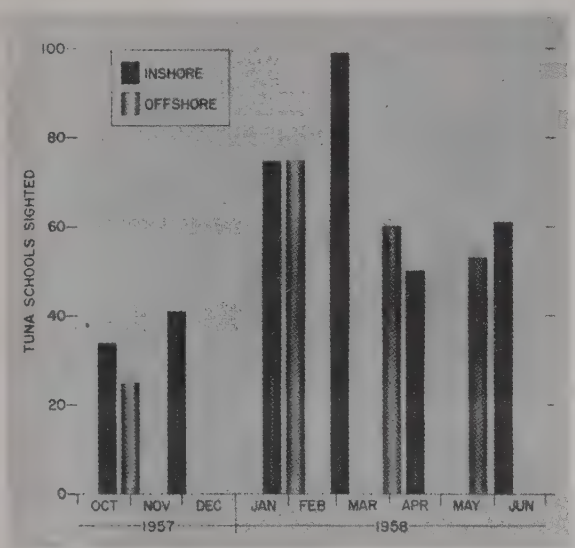
Herman Melville, "Typee."



● Many travelers have noted the myriads of sea birds about the Marquesas Islands, but it was not until the development of the tuna fisheries elsewhere that their possible economic significance was realized. Both the bird flocks and the schools of tuna have the same prey—the groups of small fish which provide their main food. More often than not, it is these flocks of birds which guide tuna fishermen to the schools.

Since mid-1956 the Pacific Oceanic Fishery Investigations (POFI) of the U. S. Fish and Wildlife Service has been engaged in a program, the primary purpose of which has been to describe the abundance of tuna schools in northeastern French Oceania, and more particularly the Marqueasas Islands. Most of the effort in this program has been focused on the Marquesas, because the group can be easily reached by the long-range segment of the American tuna clipper fleet, and the Marquesan sardine is available there as a possible supplementary supply of live bait.

The Marquesas Islands lie approximately 2,850 miles from San Diego. The group is governed by the French. They are high islands, and suitable areas for anchorage in the bays are numerous. The group lies in the belt of southeasterly trades, which are generally moderate, affording very few days when fishing cannot be carried on. Diesel fuel is not available there, but our vessels have obtained water at Taiohae, Nuku Hiva. Fresh fruit may be purchased from the Marquesans who are a Polynesian people.



Marquesan Survey results of the tuna schools scouting by POFI operations on inshore and offshore waters of the Marquesas, 2,850 miles from San Diego.

● Preliminary surveys of the area were conducted during August-September, 1956, (Marquesan winter) and January-March, 1957 (Marquesan summer). These cruises involved study of the oceanography of a broad area about the Marquesans, longline fishing for deep-swimming tunas, and surveys of the surface tuna schools in the Marquesas and Tuamotus. Results of these preliminary surveys revealed a striking difference in the abundance of tuna schools. They were about three times more abundant during the summer period (January - March, 1957) than during the winter period (August-September, 1956). Results also showed a higher concentration of inorganic phosphate and zooplankton, indices of the primary productivity of the area, during the winter.

In October, 1957, the surveys took a more definite turn, with the beginning of studies designed to determine the length of the season of greatest abundance of surface tuna schools in the Marquesas group and, to a limited extent, in the Tuamotu archipelago.

● There were two standardized types of surveys conducted, the "inshore" and the "offshore", which followed the tracks shown on Page 31. All of the

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tracks were run during daylight hours, and tuna "schools" were defined according to the following criteria:

1. Tuna school seen breaking the surface, birds may or may not be present.
2. A "working" (diving and feeding) flock of 50 or more birds seen, tuna breaking the surface may or may not be present.

Results from the inshore surveys conducted during October 1957-June 1958 (fig. 5) confirmed the greater abundance of surface tuna schools during the summer months, as follows:

Dates	Number of schools sighted
October 14-21, 1957	34
November 24-30, 1957	41
January 18-25, 1958	75
Feb. 27-March 5, 1958	99
April 11-19, 1958	50
June 1-10, 1958	61

In addition, four standardized offshore surveys were conducted, which further confirmed the seasonal nature of tuna distribution in the area:

Dates	Number of schools sighted
Oct. 24-Nov. 6, 1957	25
Jan. 28-Feb. 11, 1958	75
March 26-April 8, 1958	60
May 15-29, 1958	53

From these data it appears that within the period of the surveys, the abundance of tuna schools in the Marquesas area reached a peak during January-March, gradually tapering off thereafter.

About 80% of the identified schools were Skipjack, 15% were Yellowfin, and the remaining 5% were mixed Skipjack and Yellowfin. Virtually all of the small Yellowfin taken were from mixed schools. Of the schools of large 2- and 3-pole Yellowfin chummed, we were never successful in getting them to bite in any significant number. All of the Skipjack taken during the inshore surveys were under 10 pounds in weight, with most in the 4-6 pound weight group. However, Skipjack in the 18-22 pound weight class comprised 32% of the samples taken during the offshore surveys, with the remainder of a smaller size.

● The fishing success of POFI's research vessels is not necessarily comparable to that of a large tuna clipper because of restricted amounts of bait, fewer men in the racks, and the necessity to catch fish at a slow rate for tagging. The behavior of the schools can, in general, be described as wild and fast traveling.

The results of surveys of limited duration conducted in the northwest portion of the Tuamotu archipelago are perhaps more encouraging than those from the Marquesas. While the rate of sighting schools was lower, the schools were less wild, the fish bit better, and large Skipjack were relatively more numerous in the catch.

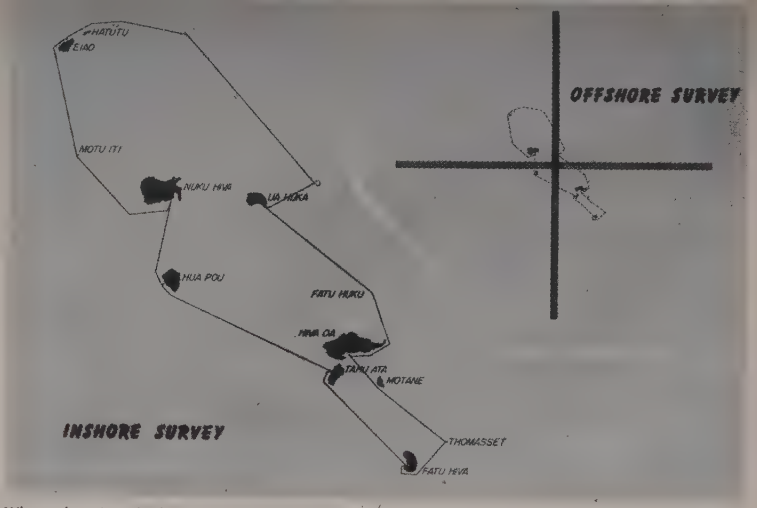
In the Marquesas and Tuamotus, 4,584 Skipjack and 196 Yellowfin have been tagged and released, using the new POFI D-2 dart tag. To our knowledge, not one of these tagged fish has been recaptured. This is in striking contrast with the 9.7% recapture of Skipjack marked with the same type tag in the Hawaiian area. Thus it appears that the absence of returns from Marquesan fish is due to lack of fishing, and that this stock is presently unexploited to any great extent.

● The bait used during the fishing surveys was the Marquesan sardine. These fish, when used as chum, remain near the surface, form small schools, and attract and hold the tuna schools near the vessel. They do not withstand extreme crowding, either during transport to the vessel, or in the wells aboard. Once adjusted to life in the baitwells, they survive well. Most of the sardines were taken in shallow water of the bays, over sandy bottom.

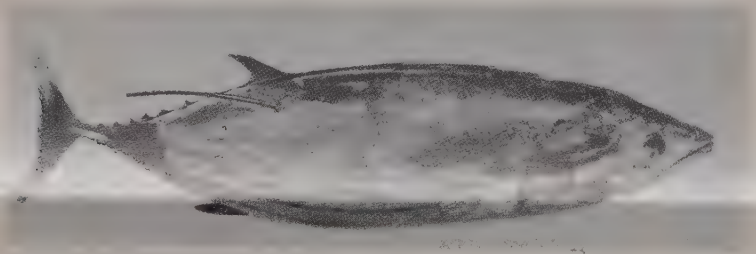
But the supply of sardines has proven unreliable. During bait surveys made in January 1957, 1,200 scoops of bait were seen in Taiohae Bay, Nuku Hiva, and 500 scoops in Anaho Bay, Nuku Hiva. However, during the period January-June 1958, our vessels had great difficulty in scratching up the small quantities (100-200 scoops) of bait needed for survey work. So we cannot state with any certainty that a tuna clipper might procure sufficient supplementary bait in the area.

Examinations of the stomachs revealed a much higher percentage of fish in their diet than was the case in Hawaiian waters. Most of the fish species in the Marquesan Skipjack stomachs were those commonly thought to be associated with the proximity of land as has also proved true in Hawaii.

The conduct of POFI descriptive and exploratory programs has in general followed three phases: First an evaluation of the area and its environment, second a study of the fishery resource, and finally, an evaluation of the commercial possibilities. The first two phases are now completed. Currently under study are plans for evaluation of the commercial possibilities by encouraging a tuna clipper to conduct full-scale commercial fishing operations in the area during the January-March, 1959, season.



Where they Searched for tuna in the waters about the Marquesan Archipelago 8° degrees below the Equator on the 140th meridian.



Oceanic Skipjack tagged with the new type of dart tag finding favor with biologists as the best means of marking tuna yet devised.

Tagging of Skipjack in Hawaiian Waters

Daniel T. Yamashita and Kenneth D. Waldron[1]

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The fishing of the Hawaiian skipjack (*Katsuwonus pelamis*) though relatively small if compared with the major fisheries of the United States, is the most important commercial fishery in the Hawaiian Islands and the only American fishery exploiting mid-ocean stocks of skipjack. Annual landings average about 11,000,000 pounds with a value to the fishermen of about one and a half million dollars.

The Pacific Oceanic Fishery Investigations (POFI), of the U. S. Fish and Wildlife Service, is engaged in a skipjack tagging program which, it is hoped, will provide information that will increase the effectiveness of the local fishery. Tagging offers a direct means of increasing our knowledge of the growth rates, general migrations, and inter-island movement of the fish. In this report we will describe the type of tags used and the results of our initial studies during the years 1954 to 1956.

A major difficulty in early tuna tagging investigations (Rounsefell and Kask, 1945; Wilson, 1953) was the lack of a suitable tag. Alverson and Chenoweth (1951) contributed to the development of a better tag by their water tunnel experiment to determine the effect of flowing water on various tags attached to frozen albacore (*Germo alalunga*). Following this work, the California Department of Fish and Game developed a tubular plastic tag (Wilson, 1953) and used it extensively for tagging albacore, yellowfin (*Neothunnus macropterus*), and skipjack tuna (Ganssle and Clemens, 1953; Blunt, 1954); this tag is often called the type G or spaghetti tag.

Prior to announcement of the successful California tag, POFI experimented with several other types, both at sea and in ponds. These tests involved internal tags and external tags of the hook and streamer type. Experiments conducted in 1950 and 1952 were either inconclusive or unpromising, so the California tag (Fig. 1) was adopted for use in Hawaiian waters from 1954 to 1956.

Application of the Tags

The type G tag was applied in the manner described by Wilson (1953), with certain modifications. Skipjack were caught by live-bait fishing methods as described by June (1951), with 3 or 4 men in the racks. A skipjack was hooked, swung up, caught by the fisherman, passed to a man designated as "holder," the tag was attached, and the fish was returned to the water. With an experienced crew a skipjack could be tagged and returned to the water in about 20 seconds.

Because it is difficult to handle skipjack without injuring them, various methods including canvas cradles, padded boxes, and electronarcosis were used in attempts to calm the fish. None of these was successful. Since it was deemed necessary to return skipjack to the water as rapidly as possible and since our efforts to quiet the fish were unsuccessful, no attempt was made to measure individual fish. Instead an estimate of the size of skipjack tagged was obtained by measuring fish which were caught and not tagged. Brock (1954) has shown that skipjack school by size, so it was believed that a reliable estimate of the size of tagged fish was obtained in this manner.

[1] Fishery Research Biologists, Pacific Oceanic Fishery Investigations, Honolulu, Hawaii. Manuscript received March 12, 1958.

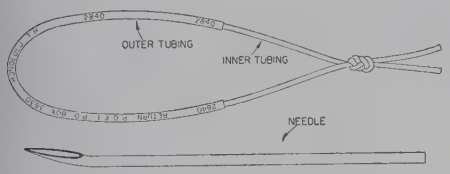

FIG. 1. California type G tag and tagging needle. Legend is on inner tubing only; serial numbers on inner and outer tubing.

Most of the skipjack tagged as described above sounded immediately upon release. On a few occasions they were seen to lead fish from the accompanying school away from the stern of the vessel. While some tagged fish left the school when released, there were indications that others remained in the same school from which they were caught. In one instance a fish released with a white type G tag was observed accompanying the vessel with part of the school for 4½ hours.

RELEASES

Between May, 1954, and July, 1956, 1,961 skipjack were tagged with the California type G tag and released in Hawaiian waters (Fig. 2).[2]

Most of the releases were within the area of the Hawaiian skipjack fishery; a few were released outside this area. This release pattern was followed in order to (1) establish the rate of recovery within the fishery, (2) study the movements of skipjack within the fishery, and (3) ascertain the direction from which skipjack approach Hawaiian waters.

It should be pointed out that the tagged fish were smaller than the usual size (18–22 pounds) composing the season's commercial landings. Eighty-five per cent were 10 pounds or smaller, 14 per cent between 11 and 20 pounds, and only 1 per cent larger than 21 pounds. The small percentage of releases in the larger size categories is due partly to the difficulty in handling these fish, and partly to the general scarcity of large fish when most of our tagging was done.

PUBLICITY PROGRAM

Publicity is an important part of most tagging programs, because one way to maximize the returns is to minimize the loss of tags recovered but not noticed by persons unaware of the program. We conducted personal interviews with skipjack fishermen on all islands and distributed posters to major fishing companies, fishing supply centers, and ports throughout the Hawaiian Islands. Fishermen were also informed of our tagging activities through radio broadcasts, transmitted by POFI vessels during their cruises in Hawaiian waters, and through informal letters. Also, wardens of the Hawaiian Division of Fish and Game stationed on the various islands were furnished photographs of tagged skipjack, together with standard recovery information forms. Because of the distinctive appearance of the tag, the publicity program, and the extensive handling of individual fish (when caught, during stowage and unloading of catch, and during butchering at the cannery), the possibility of loss of tags through nonrecognition of tagged fish was considered negligible.

Rewards for the return of tags were not part of the recovery program. Instead we purchased the tagged fish at a price slightly above the market value. A letter giving pertinent information was also sent to the person, or persons, involved in the recovery.

RECOVERIES

Of the 1,961 skipjack tagged and released, 9 were recovered by the commercial pole-and-line fishery and 3 from the stomachs of large longline-caught tunas between July, 1955, and February, 1956. The areas of release and recapture for these 12 skipjack are shown in Figure 3 and listed in Table 1. The low rate of recovery, 0.6 per cent, may be attributed in

[2] In addition, 20 skipjack were tagged with white type G tags and released in the vicinity of the Line Islands, and 12 with blue type G tags northeast of Midway Island.

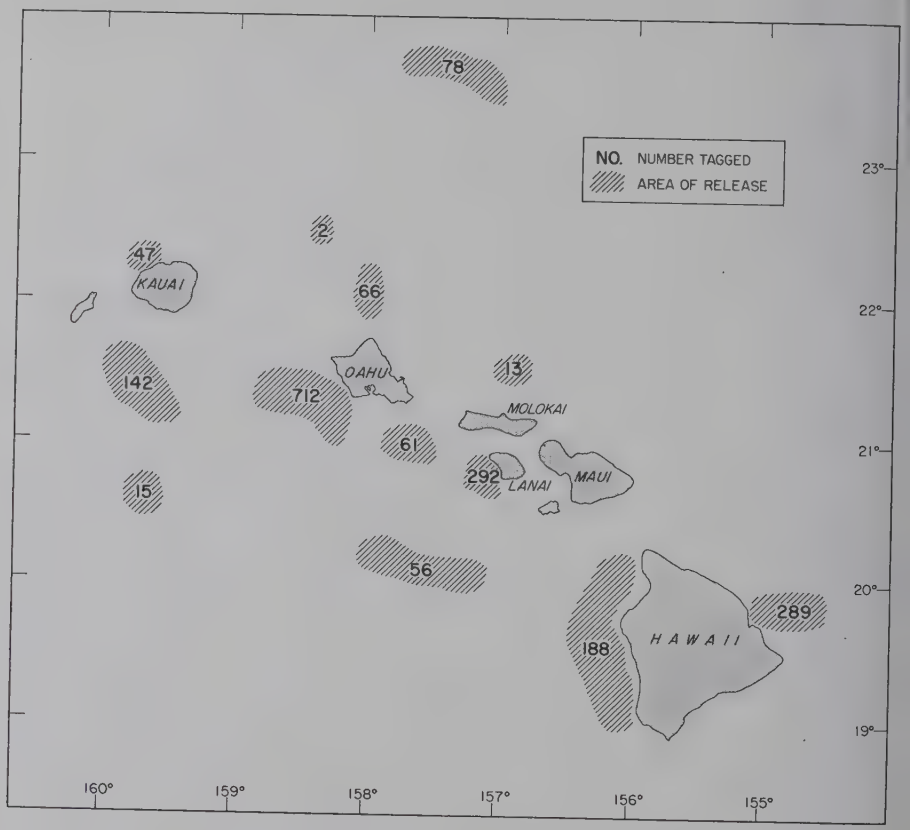

FIG. 2. Skipjack releases in Hawaiian waters, May 1954–July 1956.

part to a combination of the following factors: (1) the initial tagging mortality resulting from handling in the tagging process may have been high; (2) mortality caused by predation of large tunas and spearfishes may have been excessive; and (3) certain groups of tagged skipjack may have moved out of the area covered by the fishery.

Condition of Tags and Fish: The condition of the tag and of the skipjack was noted for each of the 9 pole-and-line caught recoveries. One fish, recaptured after only 6 days at liberty, showed quick recuperation. The tag wound appeared raw and enlarged but there were no signs of infection. Another skipjack, retaken 12 days after tagging, had new skin forming around the edges of the tag wound.

Most of the recovered fish showed a slight chafing of the anterodorsal margin of the caudal fin, caused by the free ends of the tag striking the fin. This could be prevented by trimming the ends of the tag after the knot was tied.

One skipjack recaptured 252 days after release bore only the outer jacket portion of the tag. This protruded from the right side of the fish. The wound on the left side had

TABLE 1
POFI SKIPJACK RECOVERIES WITH WHITE CALIFORNIA TYPE G TAG

ORDER OF RECOVERY	WEIGHT RANGE OF SCHOOL AT RELEASE	DATE TAGGED	DATE RECOVERED	DAYS OUT	DISTANCE TRAVELED	WEIGHT AT RECOVERY	REMARKS
	Lbs.				Miles	Lbs.	
1	5–10	6/1/55	7/12/55	41	0	3–4	Recaptured from one school
2	6–8	6/8/55	7/12/55	34	0	3–4	
3	3–5	7/20/55	7/26/55	6	40	4	
4	5–8	7/18/55	7/30/55	12	0	6	
5	3–6	8/22/55	8/24/55	2	6	3½	Found in stomach of longline-caught 189-lb. yellowfin
6	3–5	7/20/55	8/28/55	39	17	4	
7	4	8/17/55	8/17–8/26/55	0–9	0(?)	–	Tag only found in stomach of longline-caught 190-lb. yellowfin
8	3–5	8/25/55	8/25–9/1/55	0–7	0	4	Found in stomach of longline-caught 209-lb. bigeye
9	4–5	8/8/55	8/29/55	21	14	3	Recaptured from same school
10	4–5	8/8/55	8/29/55	21	14	3	
11	4–5	8/8/55	10/29/55	82	9	4½	
12	5½–9½	5/25/55	2/1/56	252	30	14	

healed completely and was marked only by a black spot on the skin (Fig. 4). Adhesion between the flesh and the plastic held the tag in place.

Movement: All of the skipjack recovered were small (3 to 10 lbs.) when tagged. They showed surprisingly little movement, all of them being recaptured within 40 miles of the point of release (Fig. 3 and Table 1). There was no inter-island movement of tagged fish. The probability of recovery of tagged skipjack in offshore waters (beyond 50 miles from land) is low because very little fishing is done in this area. However, each of the main Hawaiian islands has fisheries within 20 miles of shore, so this lack of evidence of inter-island movement cannot be attributed to the distribution of fishing effort.

Two of 39 fish (Table 1, recoveries 9 and 10) released in one group were recaptured 3 weeks later from a single school, indicating that a school of skipjack retains its identity as a unit for some time. Recoveries 3 and 6 tagged on the same day and from the same school, may provide an example of the usefulness of this hypothesis. This school may have traveled 63 miles between July 20 and August 28, 1955; 40 miles to where No. 3 was retaken, and 23 miles back to where No. 6 was retaken. Similarly, the group in which recoveries 9, 10, and 11 were released may have traveled a minimum of 37 miles between August 8 and October 29, 1955. These are straight-line distances, and in all likelihood a much greater distance was covered during this period.

Growth: Information concerning the rate of growth of skipjack was gained from a tagged fish which weighed 14 pounds when recovered after 252 days (8.4 months) at liberty. Based on the average weight of fish (7 pounds) and the size range of fish (5.5 to 9.5 pounds) in the school at the time of release, a comparison may be made with the growth rates obtained by Brock (1954) in his length frequency studies. If this tagged fish was at the lower end of the size range (i.e., 5.5 pounds) when tagged, it grew at the rate of about 1.0 pound per month. This closely approximates Brock's estimate of 1.2 pounds

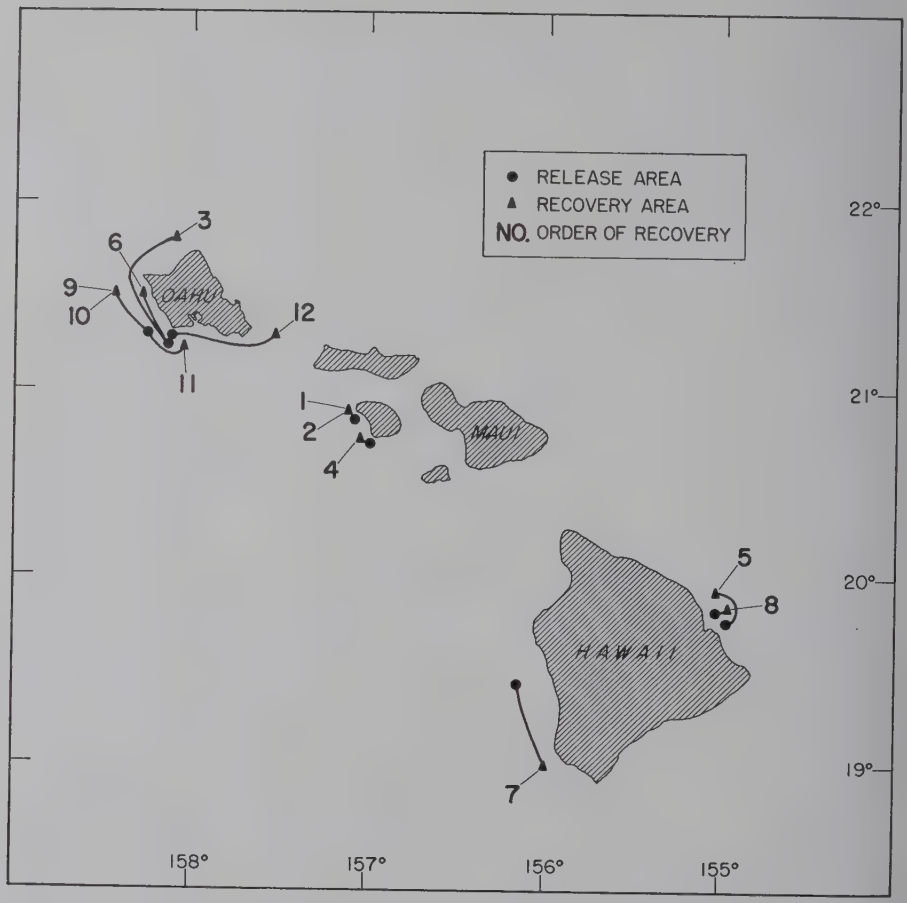

FIG. 3. Skipjack recoveries in Hawaiian waters, July 1955–February 1956.

per month for skipjack of this size (from his fig. 2). If the fish was of average size (i.e., 7 pounds) at the time of release, then a growth of 0.8 pound per month is indicated, which is slightly more than one-half the growth of 1.4 pounds per month shown by Brock. Finally, if the fish was at the upper limit of the size range (i.e., 9.5 pounds), it grew at the rate of 0.5 pound per month, or one-third the rate of growth of 1.5 pounds per month indicated by Brock.

Predation: There was evidence that some loss of tagged skipjack resulted from predation. Two tagged skipjack and one tag were recovered through incidental examination of stomachs of large tuna caught by longline near the island of Hawaii (recoveries 5, 7, 8 in Table 1). All three skipjack weighed about 4 pounds and were recovered within a few days of release. They were the only recoveries of skipjack released in that area.

In order to determine the incidence of skipjack, tagged or untagged, in the stomachs of larger fish, a sampling program at the

FIG. 4. Tagged skipjack recovered 252 days after release with only the jacket portion of the tag still in place. Dorsal view showing healed wound (dark area in circle) on the left side. Photograph by E. D. Stroup.

Honolulu auction markets was carried out between October, 1955, and June, 1956. During this interval, which included periods when skipjack were being tagged and released within the fishery, stomachs were examined from 538 bigeye (*Parathunnus sibi*), 103 yellowfin, 128 striped marlin (*Makaira audax*), and 74 black marlin (*Makaira ampla*) taken in the Hawaiian longline fishery. Twenty-eight of these stomachs (3.3 per cent) contained a total of 30 skipjack, none of which was tagged. Furthermore, only 9 of the 30 skipjack were as large as those being tagged, i.e., 2 pounds or larger, and the rest were estimated to be 1 pound or less. Only one large skipjack was taken from the stomach of a tuna; the others were from black and striped marlins. Unfortunately, there are no comparable data concerning the number of untagged skipjack from stomachs at the time the three tagged fish were found, but on the basis of subsequent sampling it seems that there was a higher rate of predation on tagged than on untagged fish.

SUMMARY

A tagging project was inaugurated to study migrations and to supplement our knowledge of growth of skipjack in Hawaiian waters.

During the period 1954–1956, California type G tags were attached to 1,961 skipjack released in Hawaiian waters. The majority of these fish weighed less than 10 pounds.

Only 12 or 0.6 percent of these fish were later recovered. This low recovery rate may be attributed to tagging mortality, predation, and movement out of the fishery.

The longest interval between release and recovery, by pole-and-line fishing, was 252 days and the shortest interval was 6 days.

Net movement was limited to 40 miles or less and no inter-island travel was shown.

The tag wounds on recovered skipjack were enlarged but well healed after 12 days. When used on smaller fish, the free ends of the tag caused chafing of the anterodorsal margin of the caudal fin.

One skipjack weighing 14 pounds at recovery grew at an estimated rate of 0.8 pound per month over an 8½-month period.

Predation by large tunas and spearfishes may be greater on tagged than on untagged skipjack. This conclusion is based on the recovery of three tagged skipjack from the stomachs of large tuna.

REFERENCES

ALVERSON, D. L., and H. H. CHENOWETH. 1951. Experimental testing of fish tags on albacore in a water tunnel. *Comm. Fish. Rev.* 13(8): 1–7.

BLUNT, C. E., JR. 1954. Two mid-Pacific recoveries of California-tagged albacore. *Calif. Fish Game* 40(3): 339.

BROCK, V. E. 1954. Some aspects of the biology of the aku, *Katsuwonus pelamis*, in the Hawaiian Islands. *Pacific Sci.* 8(1): 94–104.

GANSSLE, D., and H. B. CLEMENS. 1953. California-tagged albacore recovered off Japan. *Calif. Fish Game* 39(4): 443.

JUNE, F. C. 1951. Preliminary fisheries survey of the Hawaiian-Line islands area. Part III. The live-bait skipjack fishery of the Hawaiian Islands. *Comm. Fish. Rev.* 13(2): 1–18.

ROUNSEFELL, G. A., and J. L. KASK. 1945. How to mark fish. *Trans. Amer. Fish. Soc.* 73 (year 1943): 320–363.

WILSON, R. C. 1953. Tuna marking, a progress report. *Calif. Fish Game* 39(4): 429–442.

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